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FINAL REPORT

for the

COMPREHENSIVE ABATEMENT PERFORMANCE STUDY

VOLUME II: DETAILED STATISTICAL RESULTS

Technical Programs Branch
Chemical Management Division

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CONTRIBUTING ORGANIZATIONS

This study was funded and managed by the U.S. Environmental Protection Agency. The study was conducted collaboratively by two organizations under contract to the Environmental Protection Agency, Battelle Memorial Institute and Midwest Research Institute. Each organization's responsibilities are listed below.

Battelle Memorial Institute (Battelle)

Battelle was responsible for the design of the study, for producing the design documentation and the Quality Assurance Project Plan, for developing training for the field teams, for recruiting cooperators for the study, for providing team leaders for the field teams, for auditing the field teams, for data management of combined study data, for auditing the study data, for conducting the statistical analysis of the data, and for writing the final report.

Midwest Research Institute (MRI)

Midwest Research Institute was responsible for participating in the planning for the study, for writing certain chapters and appendices in the Quality Assurance Project Plan, for designing and producing a vacuum device for collecting field samples, for developing training for the field teams, for providing the technicians who collected the field samples, for auditing the field teams, for conducting the laboratory analysis of the field samples, for managing the data associated with the field samples, for auditing the laboratory results, and for contributing sections of the final report.

U.S. Environmental Protection Agency (EPA)

The Environmental Protection Agency was responsible for managing the study, for reviewing the design and the Quality Assurance Project Plan, for assessing the performance of the recruiters and the field teams, for reviewing audit reports, for reviewing the final report, and for arranging the peer review of the design and the final report. The EPA Work Assignment Managers were Ben Lim and John Schwemberger. The EPA Project Officers were Janet Remmers, Jill Hacker, and Phil Robinson.

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EXECUTIVE SUMMARY

In response to requirements mandated by the Lead-Based Paint Poisoning Prevention Act, in 1989 the U.S. Department of Housing and Urban Development (HUD) initiated the Lead-Based Paint Abatement Demonstration Study in seven urban areas across the U.S. The objectives of this study were to assess the cost, worker hazards, and short-term efficacy of various lead-based paint abatement methods. Among other conclusions, the FHA portion of this study estimated that abatement costs for a single-family dwelling could range from $2000 to $12,000. One question which was not answered by the HUD Abatement Demonstration was that of the long-term efficacy of the abatement methods. Therefore, in 1990 the U.S. Environmental Protection Agency (EPA), in cooperation with HUD, initiated the Comprehensive Abatement Performance (CAP) Study to address this question.

The CAP Study was a follow-up to HUD Abatement Demonstration activities performed in Denver, Colorado. There were four primary objectives of the CAP Study: (1) assess the long-term efficacy of two primary abatement methods, (2) characterize lead levels in household dust and exterior soil in unabated homes and homes abated by different abatement methods, (3) investigate the relationship between lead in household dust and lead from other sources, in particular, exterior soil and air ducts, and (4) compare dust lead loading results from cyclone vacuum sampling and wipe sampling protocols. To address these objectives, the CAP Study collected approximately 30 dust and soil samples at each of 52 HUD Demonstration houses in Denver, approximately two years after the abatements had been completed. The houses were all occupied at the time of the CAP Study field sampling, though they had not been continuously occupied between the completion of

the abatements and the field sampling. The samples were analyzed for their lead content, and these lead measurements were then used in detailed statistical analyses addressing the four study questions.

The CAP Study included two approaches for assessing abatement efficacy, one direct approach and one indirect approach. In the direct approach CAP Study lead measurements, made at HUD Demonstration houses two years after abatement, were compared with pre-abatement lead measurements made at those same houses. Since pre-abatement dust lead measurements were limited, the CAP Study also included an indirect approach to assessing abatement efficacy. In this approach, lead levels were measured in dust and soil samples collected both at abated HUD Demonstration houses, and at the same time at unabated HUD Demonstration houses found to be relatively free of lead-based paint. The performance of the abatement methods was then assessed by comparing the lead levels at abated houses with those at unabated houses. Sampling at unabated houses provided a measure of the amount of lead introduced to the housing environment from low levels of lead in paint and sources other than lead-based paint. If the environmental lead levels at abated houses were found to be similar to those at unabated houses, this was taken as an indication that abatement either lowered pre-abatement lead levels, or at least did not significantly raise lead levels at abated houses. However, if lead levels at abated houses were higher than at unabated houses, this was taken as an indication that abatement failed to completely eliminate the lead hazard because lead was introduced to these environments either immediately through inadequate dust control during abatement, or more gradually over time. Clearly, an important limitation of the direct assessment of abatement efficacy is that the pre-abatement lead levels at abated houses were not available (except for foundation soil and limited numbers for floors and window stool[1] dust), and therefore, one can only conjecture about whether the observed post-abatement lead levels represent an improvement or worsening of the housing environment.

The results of the CAP Study from the direct approach of comparing post-abatement and pre-abatement lead levels were that for the two sample types for which a comparison was possible (foundation soil and window stools), there was no evidence that post-abatement lead levels are significantly higher than pre-abatement levels. Both pre-abatement and CAP results for window stool dust samples averaged between 175 and 200 µg/ft^2. In soil at the foundation of the house, levels were near 240 µg/g. These results are based on dust lead measurements made on window stools at 10 CAP Study abated houses, as well as soil lead measurements made at 24 CAP Study abated houses. A few floor dust samples obtained from three houses were also available for comparison, but were deemed insufficient for making substantive conclusions. These results are tempered by the fact that because of the small number of houses for which data were available, as well as the large variability in observed lead levels, relatively large differences between post-abatement and pre-abatement lead levels could not be judged to be statistically significant. For example, the confidence interval for the average ratio of post-abatement to pre-abatement levels on window stools was 0.37 to 3.46. In addition, further complicating the comparison of post-abatement and pre-abatement dust and soil lead measurements was the fact that different sampling and analysis protocols were used in the CAP Study and HUD Demonstration. Perhaps most

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The window stool was defined as the horizontal board inside the window which extends into the house interior — often called the window sill. In contrast, the window channel was defined as the surface below the window sash and inside the screen and/or storm window.

significantly, the CAP Study utilized vacuum dust sampling while the HUD Demonstration utilized wipe dust sampling.

The indirect assessment of abatement efficacy found that abatement appears to have been effective, in this case in the sense that there is no evidence that post-abatement lead levels at abated houses were significantly different than lead levels at neighboring unabated houses found to be relatively free of lead-based paint. There were two exceptions to this statement; however, both of these exceptions were anticipated and are logically explained. First, lead concentrations in air ducts were significantly higher in abated houses than in unabated houses; air ducts were not abated in the HUD Demonstration. In addition, lead concentrations in the soil outside abated houses were significantly higher at the foundation and at the boundary than corresponding lead concentrations outside unabated houses. However, soil was also not abated during the HUD Demonstration; and these higher lead levels might in part be due to differences in the age of these houses, since on average the abated houses in this study were 17 years older than unabated houses. As with the caveat stated above, these results must also be tempered by the fact that not finding a significant difference in lead levels at abated and unabated houses for all other building components and sampling locations does not prove that no such differences exist. The CAP Study was designed to detect approximately two-fold differences between lead levels at abated and unabated houses under specified variance assumptions. For example, although the estimate of 1.76 for the ratio of lead loadings on floors in abated to unabated houses was not significantly different from one, the 95 percent confidence interval for this ratio was from about 0.87 to 3.5.

The CAP Study also assessed abatement by comparing encapsulation and enclosure methods versus removal methods. No significant differences among lead levels could be attributed to these two types of abatement methods, except for air ducts which, as stated above, were not abated. Air duct dust lead levels were higher in houses abated primarily by encapsulation and enclosure methods than in houses abated primarily by removal methods. It is important to note, however, that houses abated primarily by encapsulation and enclosure methods on average had greater amounts of abatement performed than houses abated primarily by removal methods. The CAP Study also performed a visual inspection of abated surfaces and recorded their condition as being intact, partially intact, or minimally intact. Less than 60% of the surfaces abated by encapsulation and chemical stripping methods were found to be intact, while more than 70% of the surfaces abated by all other methods were found intact.

With regard to the second study objective, lead levels were found to vary greatly for different media and sampling locations. Minimum individual lead concentrations for most sample types were typically on the order of 10 µg/g except in air ducts and window channels where levels were at least 50 µg/g. Maximum individual lead concentrations were lowest for boundary and entryway soil samples (1073 and 1068 µg/g, respectively) and highest for window stool and window channel dust samples (48,272 and 45,229 µg/g, respectively). Minimum individual lead loadings for all sample types were typically only 1 to 4 µg/ft^2. Maximum individual lead loadings were lowest for floor dust samples (334 µg/ft^2 by wipe and 11,641 µg/ft^2 by vacuum) and highest for window channel dust samples (244,581 µg/ft^2). Dust lead loadings were also evaluated in comparison with the HUD interim dust standards (HUD, 1990b). Geometric mean lead loadings for both floors and window stools at both abated and unabated houses were found to be well below their respective HUD standards of 200 and 500 µg/ft^2. On floors, geometric mean lead loadings were also well below the EPA guidance standard of 100 µg/ft^2 (EPA, 1994). In addition, for both of these sample types, more than 75 percent of the samples collected in the CAP Study had lead loadings below their respective HUD standards, in both abated and unabated houses. However, geometric mean window channel lead loadings at both abated and unabated houses were found to be well above the HUD interim standard of 800 $\mu g/ft^2$, and well over half of individual observations were above this standard, at both abated and unabated houses.

Three primary results were found for the third CAP Study objective. First, significant correlations in lead concentrations at the house level were found for four pairs of sample types: window channels and window stools (correlation coefficient of 0.40), entryway soil and boundary soil (0.56), boundary soil and window stools (0.38), and entryway soil and interior entryway dust (0.29). Second, at the house level, significant correlations in dust lead loadings were found for two pairs of sample types: window channels and window stools (0.56), and air ducts and exterior entryways (0.41). Third, significant correlation was observed between dust lead concentrations at interior and exterior entryways (0.37). However, at the room level, no significant correlations in dust lead loadings were found. House level correlations were based on house averages; room level correlations were based in most cases on single measurements. The fact that more house level correlations were significant suggests that differences in lead levels are more related to broad differences among houses than to location-specific characteristics within houses.

Results for the fourth study objective found that when combined across substrates, the average difference between lead loadings measured by the cyclone vacuum method and by the wipe method was insignificant. Differences were overshadowed both by large side-by-side variability in the two methods, and a strong substrate effect. This latter effect was apparently related to the smoothness of the substrate. On linoleum, the two methods were approximately equivalent, whereas on tile, lead loadings measured by the cyclone were lower than those measured by wipe, and on wood, lead loadings measured by the cyclone were higher. These results should be considered when setting environmental standards and choosing sampling methods for testing regulatory compliance.

The CAP Study results provide potentially important information about the role of relatively high-cost abatement procedures for eliminating, or controlling, residential lead-based paint. The CAP Study found no significant differences between post-abatement and pre-abatement lead levels for exterior soil and the limited number of window stool dust lead measurements available. It also found no significant differences between post-abatement lead levels at abated houses and lead levels at unabated houses, with the exception of air duct dust and exterior soil which were not abated in the HUD Demonstration. In addition, for both floors and window stools the geometric mean lead loadings at abated houses were well below the "Lead-Based Paint: Interim Guidelines for Hazard Identification and Abatement in Public and Indian Housing" (HUD, 1990b) standards of 200 and 500 $\mu g/ft^2$. The lead loading geometric mean for floors at abated houses was also well below the EPA standard of 100 $\mu g/ft^2$ for floors (EPA, 1994). These results all suggest that the abatement activities were effective, in the sense that they do not appear to have increased lead levels at abated houses above interim standards. However, the CAP Study also found that the geometric mean dust lead loading for window channels at abated houses was well above the HUD interim standard of 800 $\mu g/ft^2$, although the same result was found for unabated houses relatively free of lead-based paint.

Comparisons between the wipe method and the vacuum method used to collect dust in the CAP Study indicate that results from wipe samples would likely be below the clearance standards for floors and window stools. For window channels, differences between wipe and vacuum methods, especially on wood, preclude concluding definitively that results from wipe samples would exceed the clearance standard for window channels.

Study Conclusion

The conclusion of this study is that lead-based paint abatements are effective. This conclusion is based on the study finding that there is no evidence that post-abatement lead levels at abated houses were significantly different from lead levels at unabated houses relatively free of lead-based paint, save for two exceptions. The two exceptions, differences in lead levels between the abated and unabated houses in air ducts and exterior soil, are explained by the fact that air ducts and soil were not abated. There are caveats to the study that should be kept in mind when interpreting and assessing the results and conclusion. The principal caveats are these: no biological monitoring was done in the study, and the study was designed to detect differences approximately a factor of two or larger between the abated houses and the unabated houses.

1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION AND BACKGROUND

In response to requirements mandated by the Lead-Based Paint Poisoning Prevention Act (as amended by Section 566 of the Housing and Community Development Act of 1987), the Residential Lead-Based Paint Hazard Reduction Act of 1992, and other legislation, the U.S. Environmental Protection Agency (EPA), U.S. Department of Housing and Urban Development (HUD), U.S. Department of Health and Human Services, and other federal agencies are conducting a broad-based program of research, demonstration, and policy actions aimed at reducing the incidence of childhood lead poisoning in the U.S. An important part of the federal program is to identify and abate lead-based paint hazards in privately-owned and public housing. Toward this end, HUD initiated two important studies in 1989, the HUD National Survey of the incidence of lead-based paint in housing, and the HUD Lead-Based Paint Abatement Demonstration.

The HUD National Survey sampled both public and private housing in order to estimate the number of housing units with lead-based paint, the total housing surface area covered with lead-based paint, the condition of the paint, and the incidence of lead in household dust and surrounding soil (HUD, 1990a). The National Survey found that approximately 57 million homes, or 74 percent of all occupied housing units built before 1980, have some lead-based paint. Older homes are more likely to contain lead-based paint; 90 percent of housing units built before 1940 have lead-based paint. Within the 57 million homes there are on average 580 square feet of interior surfaces and 900 square feet of exterior surfaces covered with lead-based paint.

The HUD Abatement Demonstration was a research program in ten cities which assessed the costs and short-term efficacy of alternative methods of lead-based paint abatement. A variety of abatement methods were tested in approximately 120 multi-family public housing units in three cities -- Omaha, Cambridge, and Albany -- and similar methods were tested in 172 single-family housing units in the FHA inventory in seven metropolitan areas -- Baltimore, Birmingham, Denver, Indianapolis, Seattle, Tacoma, and Washington (HUD, 1991). The FHA demonstration evaluated two classes of abatement methods, encapsulation and enclosure methods, versus removal methods. The study found that the cost of encapsulation and enclosure abatements ranged from about $2000 to $8000 per housing unit, while the cost of removal abatements ranged from about $2000 to $12,000 per housing unit (HUD, 1990a).

Although the HUD Abatement Demonstration did assess the short-term efficacy of certain lead-based paint abatement strategies, it was not intended to evaluate the longer-term performance of these approaches. Therefore, in 1990 the EPA Office of Pollution Prevention and Toxics (formerly the Office of Toxic Substances) initiated the Comprehensive Abatement Performance (CAP) Study to further evaluate the abatement strategies used in the HUD Abatement Demonstration.

This report presents the detailed statistical results of the CAP Study. There are two reports: Volume I presents the overall study results and conclusions, while Volume II (this report) presents more detailed results from the statistical analyses performed. Within Volume I the study approach, results, and discussion of results are presented in Sections 2, 3, and 4, respectively. Among the results presented in Volume II are descriptive statistics, explanation of the statistical models, evaluation of the abatement methods, correlations among lead levels in sampled media and locations, comparison of vacuum and wipe sampling methods, comparison of CAP Study and HUD Abatement Demonstration results, results from statistical outlier analyses, and analysis of field and laboratory quality control data.

1.2 STUDY APPROACH

Whereas the HUD Demonstration was intended to focus on the short-term cost-effectiveness of abatement methods, the CAP Study provided important information about the longer-term effectiveness of these same methods. Although clearance testing of lead levels in dust was done immediately after abatement in the HUD Demonstration, the longer-term performance of the abatement methods after these houses were reoccupied was not assessed. The CAP Study was therefore necessary to preclude spending large sums of money abating lead-based paint using methods that may prove in the long term to be ineffective at maintaining low lead levels in household dust.

High levels of lead in household dust pose serious health risks to occupants regardless of the source. Therefore the CAP Study also collected important information as to how lead from other media and locations may be deposited into household dust. It is possible that lead can be redeposited in homes after the house is reoccupied where the lead-based paint hazard has been removed or contained. Either prior to abatement or during the abatement process itself, leaded dust may have been deposited in the ventilation system or other parts of the house which, when reoccupied by new residents, could spread throughout the house. Also, activity patterns of the occupants may re-introduce lead from exterior soils.

1.2.1 Study Objectives

To help address the above concerns, the specific objectives of the CAP Study were as follows:

(1) Assess the long-term efficacy of two primary abatement methods;

(2) Characterize lead levels in household dust and exterior soil in unabated homes and homes abated by different abatement methods;

(3) Investigate the relationship between lead in household dust and lead from other sources, in particular, exterior soil and air ducts, and

(4) Compare dust lead loading results from cyclone vacuum sampling and wipe sampling protocols.

These objectives were intended to address at least three important concerns presented in the HUD Comprehensive and Workable Plan (HUD, 1990a): the durability of various abatement methods over time, the importance of adequate dust control during the abatement process, and the possible redeposition of lead from a variety of locations, such as exterior soil and air ducts. The fourth objective addresses a critical issue related to the measurement and characterization of dust lead levels within a house.

The HUD Demonstration intended to eliminate the lead-based paint hazard from housing environments either by containing the lead-based paint with encapsulation or enclosure methods, or by eliminating the lead-based paint with removal methods. Encapsulation and enclosure methods attempt to chemically bond or mechanically affix durable materials over painted surfaces, while removal methods attempt to either scrape or chemically strip lead-based paint from painted surfaces, or to completely remove and replace painted components (e.g., windows, doors, baseboards).

There are at least two performance concerns with these abatement methods. First, conducting the abatement methods themselves might generate large amounts of leaded dust that could be deposited throughout the housing environment. And second, the performance of the abatement measures might degrade over several months or years following abatement, allowing the lead hazard to be reintroduced to the housing environment. Encapsulation and enclosure methods do not attempt to remove lead-based paint from housing surfaces and therefore may have a greater potential to degrade. Both encapsulation and enclosure methods, as well as removal methods have the potential to spread leaded dust throughout the housing environment during abatement.

For the CAP Study, the ideal direct approach to assessing the long-term efficacy of the abatements performed in the HUD Demonstration would have been to collect pre-abatement dust and soil lead measures, and compare them with measures collected after abatement at the same locations. If the post-abatement measurements were not higher than pre-abatement lead levels, this could be taken as an indication that abatement had a positive effect on the housing environment. While the CAP Study did perform this direct assessment of abatement efficacy, only foundation soil samples and a limited number of dust samples were taken during the HUD Demonstration prior to abatement. Thus, only limited *direct* information could be obtained about the effects of abatement.

Realizing these limitations, the approach for addressing the first objective of the CAP Study also included an indirect assessment of abatement efficacy. In this second approach post-abatement dust and soil samples were collected and chemically analyzed for lead approximately two years after abatement both at abated houses, and at the same time at unabated houses known to be relatively free of lead-based paint. The performance of the abatement methods was then assessed by comparing the lead levels at abated houses with those at unabated houses. Sampling at unabated houses provided a measure of the amount of lead introduced to the housing environment from low levels of lead in paint and sources other than lead-based paint abatement. If the environmental lead levels at abated houses were found to be similar to those at unabated houses, this was taken as an indication that abatement either lowered pre-abatement lead levels, or at least did not significantly raise lead levels. However, if lead levels at abated houses were significantly higher than those at unabated houses, this was taken as an indication that abatement failed to completely eliminate the lead hazard because lead was introduced to these environments either immediately through inadequate dust control during abatement, or more gradually through redeposition over time.

Comparing post-abatement levels of lead in abated houses to levels in unabated houses does not necessarily reflect the degree to which abatement lowered levels of dust and soil lead compared to pre-abatement levels. However, it does provide a basis for discerning whether abatement reduces dust and soil lead levels to levels present in houses with no apparent need for abatement (based on portable X-ray fluorescence readings of lead levels in paint). The levels of lead in dust and soil were primarily assessed by the concentration of lead present in samples, measured as the weight of lead (in micrograms, µg) in a sample divided by the total weight of the sample (in grams, g). Higher lead concentrations at abated houses were generally taken as an indication that paint had contributed additional lead to the environment over that which had been deposited from other non-paint sources, such as prior fallout from automotive emissions. For dust, the lead levels were also assessed by the lead loading present, which is measured as the weight of lead (µg) collected in a sample divided by the total surface area sampled (in square feet, ft^2). The lead loading, which takes into account both the lead concentration present as well as the dustiness of the environment, provides a measure that can be combined with room dimensions to assess the total amount of lead to which residents are exposed.

1.2.2 Study Design

Of the 172 single-family dwellings abated during the HUD Abatement Demonstration, three of these houses had pilot abatements performed, while the other 169 were completely abated. Soil was not abated at any of these houses. The distribution by city of these 169 houses is presented in Table 1-1. The specific houses for abatement were selected by first identifying older

Table 1-1. Number of Houses Abated in the HUD Demonstration

City	Interior Abatement Category*		Exterior Abatement Only**		Total
	Encap/ Enclos	Removal	Encap/ Enclos	Removal	
Baltimore	11	9	--	--	20
Birmingham	8	12	2	1	23
Denver	33	18	5	1	57
Indianapolis	17	10	3	4	34
Seattle/Tacoma	12	10	1	3	26
Washington	6	3	--	--	9
Total	87	62	11	9	169

* Each house was classified according to the abatement category accounting for the largest square footage of interior abatement.

** For houses having only exterior abatement performed, each house was classified according to the abatement category accounting for the largest square footage of exterior abatement.

housing likely to contain lead-based paint and then testing painted surfaces for lead using portable X-ray fluorescence (XRF). Houses abated in the HUD Abatement Demonstration were those found to have a significant number of structural components covered by paint with a high concentration of lead. When surveying houses for lead-based paint, HUD considered all painted surfaces both on the interior and exterior of the house.

The HUD Demonstration originally included six different abatement methods: encapsulation, enclosure, and four removal methods (i.e., chemical stripping, abrasive stripping, heat-gun stripping, and complete removal or replacement of painted components). Because of the diversity of housing components containing lead-based paint, it was generally true that no single abatement method could be used uniformly throughout a given house. One important consideration in the CAP Study was the appropriate way in which to summarize and classify the abatement activities conducted at each house. Detailed information was collected by HUD which listed each type of interior and exterior structural component abated in the Demonstration, along with the linear or square footage abated and the abatement method used. For the CAP Study, each house was primarily classified according to the abatement category (i.e., encapsulation/enclosure versus removal methods) accounting for the largest square footage of interior abatement. However, at many HUD Demonstration houses, a great deal of exterior abatement was also performed. Therefore, the data interpretation also considered which specific methods were used on both the interior and exterior of the house. Two other important considerations for the data interpretation are the sometimes widely different square footages abated at different houses and the different mix of methods used.

Selection of Abated Housing Units

Initial plans for the CAP Study included selection of housing units from all seven urban areas in the FHA portion of the HUD Demonstration. However, after conducting a pilot sampling and analysis program (EPA, 1995a), and subsequently developing a cost estimate for the CAP Study, it was decided that the CAP Study would only be conducted in Denver, where 57 of the 169 abated houses were located (Table 1-1). Because the number of abated houses in Denver was limited, all reoccupied houses were initially included for recruitment in the CAP Study. A preliminary statistical power analysis was conducted to examine the magnitude of the differences between dust lead levels in abated and unabated houses that could be detected with 80 percent power. The analysis utilized the available information about both the abated and unabated houses in Denver, as well as the results from the CAP Pilot Study. For the purposes of the analysis, it was assumed that two abated houses would be sampled for every one unabated house sampled. Power analysis results indicated that approximately 40 abated houses (and therefore 20 unabated houses) would be sufficient to detect two-fold differences between the dust lead levels in abated and unabated houses. (This analysis is described in detail in Appendix F.) Given the initial set of 57 abated houses in Denver, 70% of these houses had to be successfully recruited into the study.

Selection of Unabated Housing Units

Only foundation soil samples and a limited number of dust samples were collected at the abated houses prior to abatement. This hindered the use of each abated house as its own control to provide a direct assessment of abatement performance. Therefore, in order to use the levels of lead measured in dust and soil samples at abated houses as a measure of the performance of abatement at those houses, lead levels associated with other environmental sources had to be characterized. Therefore, in addition to abated houses, dust and soil samples were collected from unabated houses that were previously tested by XRF in the HUD Demonstration and found to be relatively free of lead-based paint. The objective in measuring lead levels at unabated houses was to determine whether lead levels observed at abated houses were in fact greater than those found at houses having very few components covered with lead-based paint and therefore presumably affected primarily by non-paint sources of lead.

Some consideration was given to the idea of including a second type of unabated house, where significant amounts of lead-based paint were known to be present, and no abatement activities had yet been performed. Presumably, environmental lead levels measured in interior dust and exterior soil at these houses would have been significantly higher than those measured at abated houses and at houses that were known to be relatively free of lead-based paint. Houses with unabated lead-based paint could have supplied at least two additional interesting comparisons to the CAP Study:

- If it were demonstrated that no significant difference exists between environmental lead levels at houses with unabated lead-based paint and houses that contain relatively little lead-based paint, then this result might suggest that non-paint sources of lead dominate the housing environment.

- If environmental lead levels at abated houses were found to be significantly lower than those with unabated lead-based paint hazards, then this would indirectly suggest that abatement is successful in lowering lead levels at houses with lead-based paint.

Although these and other comparisons would have been quite informative, houses with unabated lead-based paint were not included in the CAP Study. The primary reason for excluding these houses was that they should be subsequently abated to protect residents' safety; however, EPA could not identify a suitable mechanism to conduct these abatements.

In the FHA portion of the HUD Demonstration, a total of 132 houses were tested by XRF for lead-based paint, but were not abated (Table 1-2). When performing the XRF tests, three replicate XRF readings were made at each sampling location and decisions at each location were based on the average of those three readings. When interpreting the results, an average reading greater than or equal to 1.0 mg/cm^2 was considered to be a positive indication that lead-based paint was covering the tested component. While only a single round of XRF testing was performed at unabated houses, in some cases a second round of XRF and/or AAS testing was performed at abated houses to confirm inconclusive XRF results.

Unabated houses for the CAP Study were recruited from the set of unabated houses in Denver that were tested by XRF in the HUD Demonstration. For the purpose of identifying unabated houses, the detailed XRF results were used under the assumption that they provided an accurate and current assessment of these houses. Using a criterion that equally weighted (1) the percentage of housing components testing positive by XRF for lead-based paint, and (2) the average XRF testing result, the 40 unabated houses in Denver were prioritized. Seventeen unabated houses were sampled for the CAP Study, including 16 houses from

Table 1-2. Number of Unabated Houses Tested by XRF in the HUD Demonstration

City	Number of LBP Building Components*				Total
	0	1-2	3-9	10 or More	
Baltimore	1	6	3	10	20
Birmingham	4	5	--	5	14
Denver	13	10	14	3	40
Indianapolis	5	9	5	--	19
Seattle/Tacoma	10	3	2	5	20
Washington	4	2	4	9	19
Total	37	35	28	32	132

* Number of structural components for which XRF testing identified the presence of lead-based paint.

among the 31 with the lowest XRF results, and a 17th house which was 36th on the prioritized list. The 36th house on the prioritized list was recruited because it was the duplex to the 27th house which had already been recruited.

Recruitment of Housing Units

The FHA regional property disposition office in Denver was contacted with a request to complete a record of property disposition form for each abated and unabated home in the region. From this form the following data were obtained: name, address and telephone number of the purchaser; date of settlement; investor versus owner/occupant status of purchaser; date property was listed for sale; an indication of whether the house was cleared after abatement; and ages of children of owner/occupants.

Appointments were scheduled with residents using a combination of mailed information packets, telephone calls, and on-site visits by a recruitment team. A total of 83 houses (32 unabated, 51 abated) were approached during the recruitment phase of the CAP Study. Appointments were confirmed and two field teams collected samples during March and April of 1992 from 52 of these houses (17 unabated, 35 abated). Eight houses (5 unabated, 3 abated) refused to participate in the study. Remaining houses were either vacant or unreachable. An audit of the field sampling activities was performed during the second week of sampling. No significant problems were identified during this audit.

Selection of Rooms in Housing Units

Generally, two rooms were randomly selected from each housing unit for sampling. In unabated houses, the two rooms were selected from those rooms where XRF measurements had been taken in the room, and the average XRF reading was less than or equal to 0.2 mg/cm^2. In abated houses, where possible two rooms were selected with at least 50 square feet of abatement. However, this was not possible in 18 of the abated houses. In these houses, one unabated room was then selected where the average XRF reading was less than 0.2 mg/cm^2. Unabated rooms were sampled to determine whether abatement in other rooms of these houses may have caused increased lead levels in the unabated rooms. Additionally, in 13 houses with higher abatement square footages and two abated rooms already being sampled, an unabated room was also sampled. This was done to avoid a potential bias in the study results toward contrasts in houses requiring small amounts of abatement.

Design Limitations

There were certain specific limitations in the design of the CAP Study which are important to mention. The primary design limitation forms the basis for sampling unabated houses. As discussed above, to assess abatement efficacy one would ideally like to compare pre-abatement levels in each house with levels observed after abatement. This direct type of comparison was performed to the extent possible, however only foundation soil and a limited number of dust measures taken prior to abatement were directly comparable to the measures taken in the CAP Study. Therefore, an indirect measure of the effect of abatement was obtained by comparing post-abatement levels with levels in houses previously identified as relatively free of lead-based paint.

Another important design limitation was that the CAP Study houses abated primarily by encapsulation/enclosure methods had, on average, more abatement performed than those abated primarily by removal methods. Therefore, it is possible that any higher lead levels found in encapsulation/enclosure homes may be attributable to greater initial lead levels and greater amounts of lead-based paint present.

In addition, other minor distinctions exist among the groups of houses which should be understood in interpreting the results. The discussion of significant factors provided in Sections 3 and 4 of this report details dependencies of the factors related to abatement group. For example, on average, abated houses were 17 years older than unabated houses. This fact was controlled for in estimating the effect of house age.

1.2.3 Sampling Design

During the CAP Study a variety of environmental samples were collected along with questionnaire and field inspection information to help assess the performance of abatement methods used in the HUD Demonstration. The environmental samples that were collected are summarized in Table 1-3. All samples were chemically analyzed to measure the amount of lead present. The results for vacuum dust samples were presented on both a concentration basis (i.e., micrograms of lead per gram of dust, µg/g) and a loading basis (i.e., micrograms of lead per unit area sampled, µg/ft^2). Only lead loading results were presented for wipe dust samples and only lead concentration results for soil core samples. All houses were sampled during a five-week period in late winter/early spring of 1992. Although seasonal variations have been documented in previous studies (EPA, 1995c), this short sampling interval reduced the need to control for such variations in comparisons associated with the study objectives.

The environmental sampling planned for the study included both regular samples (vacuum dust and soil cores) and field quality control samples (wipe versus vacuum dust, blanks, and side-by-side samples) intended to assess sampling variability and potential sample contamination. Field quality control samples were collected using the same procedures as regular samples. The role of each type of sample listed in Table 1-3 for meeting these objectives was as follows:

- Vacuum dust from floor perimeter and window stools -- Provided primary measure of performance for interior abatement (the window stool was defined as the horizontal board inside the window--often called the window sill);

- Vacuum dust from window channels -- Provided measure of performance for interior abatement, possible measure of performance for exterior abatement, and possible transport of exterior soil from outside to inside the house (the window channel was defined as the surface below the window sash and inside the screen and/or storm window);

- Vacuum dust from air ducts -- Primarily to provide measure of lead level in dust that has not been disturbed by cleaning and may be more indicative of previous levels of lead in the household dust at a particular home; provided measure of source contribution to interior dust lead levels;

- Vacuum dust from interior and exterior entryway floor -- Provided measure of possible transport of exterior soil from outside to inside the house;

- Soil cores -- Combined with pre-abatement measures, provided primary measure of performance of exterior abatement. Also provided measure of possible transport of exterior soil lead into the house.

Table 1-3. Summary of Environmental Sampling Planned for the CAP Study

Sample Type	Number of Samples Planned		
	For 17 Unabated houses	For 22 Abated Houses[(a)]	For 13 Abated Houses[(b)]
Regular Samples			
1. Vacuum dust			
a. Perimeter floor	2	2	3
b. Window channel	2	2	3
c. Window stool	2	2	3
d. Air ducts	2	2	3
e. Int. entryway floor	2	2	2
f. Ext. entryway concrete	2	2	2
2. Soil cores			
a. Near foundation	2	2	2
b. Property boundary	2	2	2
c. Entryway	2	2	2
Quality Control Samples			
3. Wipe vs. vacuum			
a. Floor wipe dust	0	2	2
b. Floor vacuum dust	0	2	2
4. Blanks			
a. Vacuum dust field blank	1	1	1
b. Vacuum dust trip blank	1	1	1
c. Soil core field blank	1	1	1
d. Wipe dust field blank	0	1	1
5. Side-by-side samples			
a. Vacuum dust floor	1	1	1
b. Soil cores	1	1	1

Total Samples	23	28	32

(a) 22 houses where sampling was conducted in two rooms.
(b) 13 houses where sampling was conducted in three rooms.

- Wipe versus vacuum dust from floors -- Provided consistency check against earlier results from HUD Demonstration and other studies by examining dust levels sampled using vacuum and wipe procedures from adjacent surfaces (recall that the HUD Demonstration Study collected wipe dust samples);

- Vacuum, wipe, and core blank samples -- Provided assessment of potential sample contamination and uncertainty in sample weighing; and

- Vacuum dust and soil core side-by-side samples -- Provided assessment of short-scale sampling variability.

Interior and Exterior Dust

Rooms were selected for sampling primarily to collect floor, window stool, and window channel dust samples. Some of the most important points related to dust sampling are as follows:

- Sampling was in general performed in two different rooms of each unabated house -- this provided a measure of the variability in background lead levels within a house.

- With one exception, sampling was performed in either 1 or 2 abated rooms for each abated house -- sampling 2 abated rooms provided a measure of the variability in abatement performance within a house*.

- Sampling was performed in 1 unabated room in most abated houses** -- the CAP Study pilot sampling and

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No abated rooms were sampled in one abated house – this house had only exterior abatement performed. One abated room was sampled in 18 abated houses. Two abated rooms were sampled in 16 abated houses.

No unabated rooms were sampled in three abated houses. One unabated room was sampled in 29 houses. Two unabated rooms were sampled in three houses.

analysis program demonstrated that unabated rooms in abated houses may contain significant amounts of leaded dust (EPA, 1995a). This leaded dust may be due to undetected and unabated lead-based paint in unabated rooms, or to deposition from abatements performed in other rooms of the house.

- If the rooms selected for sampling did not contain an entry, or if there were no air ducts present, or if side-by-side vacuum/wipe comparison samples could not be collected there (e.g., rooms were carpeted), additional rooms were selected from which these samples could be collected.

- Abated rooms in abated houses were randomly selected from rooms with at least 50 ft^2 of abatement performed. In houses where the required number of rooms satisfying this condition was not available, rooms with the largest square footage abated were selected.

- In each of the rooms targeted for sampling, sampling was performed on floors, window channels, and window stools. For abated houses this provided a means to assess differences in the way an abatement method performed with respect to different structural components, and for unabated houses this provided a further measure of the within-house variability of background lead levels.

- In each abated house, an uncarpeted room was selected in which to compare the vacuum and wipe dust sampling protocols. To perform this comparison, two vacuum samples and two wipe samples (each sample from a 1 ft^2 area) were collected side by side in a random configuration from the floor perimeter. Where possible, these samples were collected from one of the originally selected rooms, but in some cases, it was necessary to select an additional room. (See previous footnotes * and **.)

- Sampling was performed in one supply air duct in each selected room; in cases where more than one supply air duct was available in a room, the air duct for sampling was randomly selected from those available. If no airducts were available in a room, then (where possible) an air duct was selected from a nearby room.

- Sampling was performed immediately inside and outside the front and rear entryways of each house -- for both abated and unabated houses, these samples provided a means of assessing possible transport of lead from exterior to interior locations.

Exterior Soil

As noted earlier, the HUD Demonstration evaluated the abatement of both interior and exterior painted surfaces, and in fact, for many houses exterior abatement was the most significant activity performed. Furthermore, the same abatement method might be expected to perform quite differently on interior and exterior surfaces. Therefore, the CAP Study evaluated both interior and exterior abatement.

Exterior foundation soil sampling provided the primary means for assessing the effects of exterior lead-based paint and abatement. In this assessment, lead concentrations measured in soil samples taken close to the foundation were compared with those measured in samples taken at the property boundary which were as far as possible from the foundation, and therefore, primarily affected by only background sources of lead, rather than lead-based paint. During the HUD Demonstration, no soil abatement was performed. Therefore, if elevated lead levels were found in the foundation soil, they could be due either to the earlier presence of lead-based paint, or to the exterior abatement activities. It is also possible that airborne lead deposition may be greater in the vicinity of walls than in open areas.

Some of the most important points to note for the soil sampling are as follows:

- Soil samples were collected both at the foundation of each house and at the property boundary -- for abated houses this provided a measure of both soil potentially affected by lead-based paint and/or abatement (i.e., at the foundation) versus soil affected mostly by background sources (i.e., at the property boundary);

for unabated houses this provided a measure of the spatial variations in background soil lead levels.

- Samples were collected from two randomly selected sides of the house -- for abated houses this provided a measure of the variability in lead-based paint and/or abatement performance effects, while for unabated houses this provided another measure of the spatial variations in background soil lead levels.

- Samples were collected immediately outside the front and rear entryways -- for both abated and unabated houses this provided a means for assessing possible transport of exterior lead into the house.

1.2.4 Sample Selection, Collection And Analysis Procedures

For dust collection, a cyclone vacuum was the primary sampling device used. The area vacuumed was nominally 1-ft^2 for floor samples, and nominally the entire accessible surface for window stools, channels, and air ducts. Two one-square foot wipe samples of surface dust were also collected from uncarpeted floors in abated houses.

Soil samples were collected with a soil recovery probe consisting of a 1-inch internal diameter plastic butyrate liner and a 12-inch stainless steel core sampler with cross-bar handle and hammer attachments. Each sample was a composite consisting of three soil cores, each 0.5 inches in depth as measured from the top of the soil surface. A new plastic liner was used for each sample, and the probe was cleaned with wet disposable wipes between each sample. To reduce cross-contamination, only the plastic liner was used where soil conditions allowed.

Sample preparation procedures for dust and soil samples were carried out using versions of EPA SW846 Method 3050, which included use of nitric acid and hydrogen peroxide for sample digestion. Sample digestates for all sample types were analyzed for lead levels using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) at the 220 nanometer emission line.

1.3 STUDY RESULTS

This section provides a summary and analysis of the CAP Study results. The statistical methods, models, and results are more completely described later in this report. The discussion of results is organized according to the study objective to which they pertain.

1.3.1 Assessment of Long-Term Abatement Efficacy

The CAP Study included two approaches for assessing abatement efficacy, one direct approach and one indirect approach. In the direct approach CAP Study lead measurements, made at HUD Demonstration houses two years after abatement, were compared with pre-abatement lead measurements made by HUD at those same houses. The indirect approach involved comparing lead levels measured in dust and soil samples collected both at abated HUD Demonstration houses, and at the same time at unabated HUD Demonstration houses found to be relatively free of lead-based paint.

Comparison of Pre-Abatement and Post-Abatement Lead Levels

The results of the CAP Study from the direct approach of comparing post-abatement and pre-abatement lead levels follow.

> ***Post- vs. Pre-Abatement.*** For the two sample types for which a comparison was possible, that is window stools and exterior soil, there was no evidence that post-abatement lead levels were significantly higher than pre-abatement levels. Pre-abatement lead loadings and lead loadings measured during the CAP Study averaged between 175 and 200 $\mu g/ft^2$. Pre-abatement foundation soil lead concentrations and lead concentrations measured during the CAP Study averaged near 240 $\mu g/g$.

This result is based on 21 dust lead measurements made on window stools at 10 CAP Study abated houses, as well as 45 soil lead measurements made at 24 CAP Study abated houses.

These results are tempered by the fact that because of the number of houses for which data were available, as well as the large variability in observed lead levels, relatively large differences between post-abatement and pre-abatement lead levels could not be judged to be statistically significant. For example, the confidence interval about an average ratio of post-abatement to pre-abatement levels for window stools was 0.37 to 3.46. This means that even if post-abatement levels were 3 times higher than pre-abatement levels, they would not be judged to be significantly higher. In addition, further complicating the comparison of post-abatement and pre-abatement dust and soil lead measurements was the fact that different sampling and analysis protocols were used in the CAP Study and HUD Demonstration. Perhaps most significantly, the CAP Study primarily utilized vacuum dust sampling while the HUD Demonstration exclusively utilized wipe dust sampling.

Modeling Results

Table 1-4 provides a summary of the sample types and abbreviations used to represent each sample type in subsequent

Table 1-4. Symbols Used to Denote Sample Types in Tables and Figures

Sample Type	Symbol	Description
Dust	ARD	Vacuum dust samples collected from an air duct within the unit
	WCH	Vacuum dust samples collected from a window channel within the unit
	WST	Vacuum dust samples collected from a window stool within the unit
	FLW	Wipe dust samples collected from a floor within the unit
	FLR	Vacuum dust samples collected from a floor within the unit
	EWI	Vacuum dust samples collected from inside an entryway to the unit
	EWO	Vacuum dust samples collected from outside an entryway to the unit
Soil	EWY	Soil core samples collected adjacent to an entryway to the unit
	FDN	Soil core samples collected at the foundation of the unit
	BDY	Soil core samples collected at the boundary of the property

tables and figures. The results of the CAP Study from the indirect approach of comparing post-abatement lead levels at abated houses with lead levels at unabated houses relatively free of lead-based paint were determined by fitting a series of statistical models to data collected for all sample types, that is, dust and soil sampled at several different locations. Table 1-5 displays estimates of the effects of the primary abatement factors on lead loadings and lead concentrations. The third column of Table 1-5 provides the number of samples included in the model for each sample type. The fourth column contains the estimated geometric mean in houses which were not abated. The log standard error of these estimates appears in parentheses below each estimate. The estimated geometric mean is to be interpreted as the average lead level in typical unabated houses.

Table 1-5. Estimates[a] of Effects of Primary Abatement Factors on Lead Loading and Lead Concentration; Controlling for Significant Covariates

(1) Response	(2) Sample Type	(3) No. Samples/ Denominator Degrees of Freedom	(4) Geometric Mean[b]	(5) Ratio of Abated to Unabated[c]	(6) Ratio of E/E to Removal[d]	(7) Ratio of Unabated Rooms to Abated Rooms[e]
Lead Loading (μg/ft²)	Air Duct (Vacuum) [ARD]	86 (35)	76 (0.52)	4.70 (0.61) .016	3.99 (0.68) .049	0.73 (0.39) .432
	Window Channel (Vacuum) [WCH]	86 (33)	1604 (0.60)	0.86 (0.68) .831	0.54 (0.80) .448	0.39 (0.53) .091
	Window Stool (Vacuum) [WST]	113 (60)	38.1 (0.39)	1.84 (0.50) .231	2.51 (0.57) .111	0.67 (0.43) .366
	Floor (Wipe)[f] [FLW]	65 (32)			0.93 (0.34) 0.833	
	Floor (Vacuum) [FLR]	233 (105)	16.2 (0.29)	1.76 (0.35) .105	2.02 (0.36) .053	0.56 (0.33) .087
	Entryway (Interior Vacuum) [EWI]	90 (34)	191 (0.31)	1.05 (0.38) .902	1.15 (0.44) .754	1.63 (0.41) .244
	Entryway (Exterior Vacuum) [EWO]	97 (46)	220 (0.37)	2.24 (0.44) .071	1.09 (0.50) .869	
Lead Concen-tration (μg/g)	Air Duct (Vacuum) [ARD]	86 (35)	332 (0.19)	1.59 (0.23) .049	2.01 (0.24) .006	0.79 (0.23) .301
	Window Channel (Vacuum) [WCH]	83 (29)	851 (0.44)	0.98 (0.51) .970	1.46 (0.59) .529	0.61 (0.40) .217
	Window Stool (Vacuum) [WST]	113 (60)	416 (0.30)	1.70 (0.39) .176	1.77 (0.44) .199	0.69 (0.31) .251
	Floor (Vacuum) [FLR]	233 (105)	137 (0.18)	1.03 (0.22) .888	1.30 (0.23) .258	0.87 (0.22) .534
	Entryway (Interior Vacuum) [EWI]	90 (34)	183 (0.22)	0.85 (0.27) .561	0.95 (0.31) .876	1.28 (0.26) .341
	Entryway (Exterior Vacuum) [EWO]	97 (46)	184 (0.22)	1.19 (0.26) .509	1.01 (0.29) .976	
	Entryway (Soil) [EWY]	109 (12)	126 (0.18)	1.48 (0.21) .087	1.26 (0.24) .365	
	Foundation (Soil) [FDN]	88 (14)	86 (.14)	1.82 (0.20) .009	0.81 (0.28) .452	
	Boundary (Soil) [BDY]	120 (20)	86 (0.13)	1.63 (0.15) .004	1.27 (0.18) .205	

[a] Top value in columns 5-7 is multiplicative estimate, middle value is logarithmic standard error of estimate, and bottom value is observed significance level.

[b] Geometric mean in unabated houses after controlling for effects of significant factors.
[c] Ratio of levels in abated rooms of abated houses to those in unabated houses.
[d] Ratio of levels in E/E houses to those in removal houses.
[e] Ratio of levels in unabated rooms of abated houses to those in abated rooms of the same houses.
[f] Floor wipe samples were only collected in abated houses; the geometric mean in abated houses was 11.3 μg/ft^2 after controlling for significant factors.

That is, it represents the estimated average when the significant covariates included in the model are fixed at the nominal levels (e.g., typical unabated house was owner occupied, built in 1943, etc.). Nominal levels and effects of these factors are discussed in Section 4 of this report.

The fifth column in Table 1-5 displays the estimated ratio of levels in abated rooms of typical abated houses to levels in typical unabated houses. The abated houses were divided into two categories, according to their predominant method of abatement: encapsulation/enclosure (E/E) or removal. The sixth column contains the estimated impact of abatement method, which should be interpreted as the ratio of levels in abated rooms of typical E/E houses to levels in abated rooms of typical removal houses (a precise definition of "typical" is provided in Volume II). The seventh column in this table gives an estimate of the ratio of levels in unabated rooms of abated houses to levels in abated rooms of abated houses. The log standard error and significance level appear beneath each of these estimates. The latter represents the observed significance of a test that the ratio equals 1.

The models used to estimate these primary effects included various secondary abatement factors and additional non-abatement factors. Secondary abatement factors included total square feet abated by each method, the abatement contractor, phase of abatement, and XRF measures taken during the HUD Demonstration. The non-abatement factors included those related to sampling substrate and protocol deviations, as well as resident-related factors such as cleanliness, ownership, occupation, and activities. The specific factors included in each model and their effects are described in detail in Section 4 of this report.

In the subsequent discussion of the results, an effect is described as being "statistically significant" if the associated p-value is less than 5 percent. The reader is referred to

Appendix C of this report for specific p-values. These p-values can be interpreted as the probability that the observed result may have occurred simply by chance. Therefore, small p-values represent situations where the results are unlikely to be simply chance events.

The estimated ratios in Table 1-5 (i.e., columns 5-7) are displayed graphically in Figures 1-1 and 1-2 for lead loading and lead concentration, respectively. Reference lines are provided on these plots at a level of one (1) which indicates that the lead levels in both types of houses or rooms were equal. An asterisk indicates that the effect was significant at the 5 percent level. A bar which rises above the reference line for the 'Abatement' factor indicates that for this sample type levels were higher in abated houses than in unabated houses. A bar which rises above the reference line for the 'Method (E/R)' factor indicates that the levels in E/E houses were higher than those in removal houses. If the 'Unabated room' effect is greater than one, then levels in unabated rooms of abated houses were higher than in abated rooms. The results presented in this table and these figures are discussed in the subsequent sections.

Comparison of Levels in Abated and Unabated Houses

The first objective of the CAP Study was to assess the long-term efficacy of abatements performed in the HUD Demonstration Study. The following conclusions can be made from the CAP Study results.

> ***Abated vs. Unabated Houses.*** Only in air ducts and soil were geometric mean lead levels significantly higher in abated houses than in unabated houses. In soil, lead concentrations were significantly higher than corresponding levels outside unabated homes at the foundation and at the property boundary. Neither soil nor air ducts was abated in the HUD Demonstration.

As indicated in the fifth column of Table 1-5, lead concentrations were about 1.6 times higher in the air ducts of

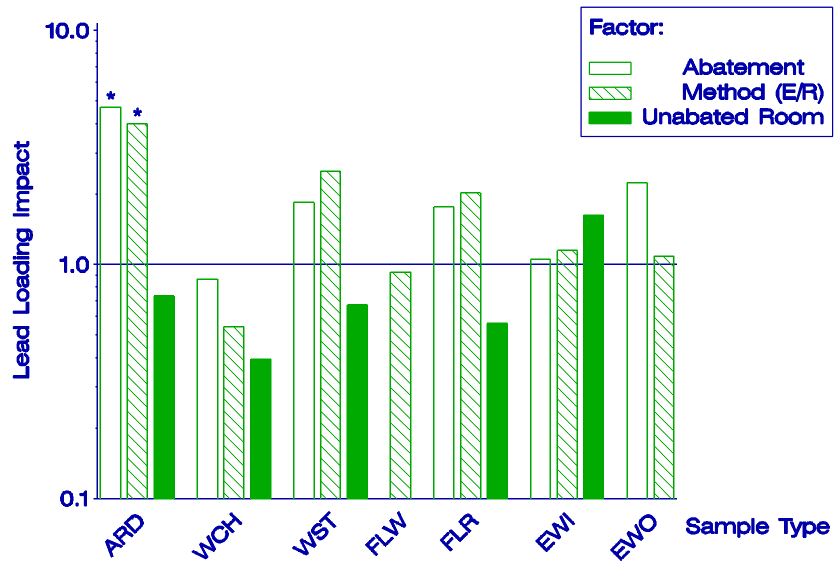

Figure 1-1. Estimated multiplicative effects of abatement from mixed model ANOVA: Lead Loading.

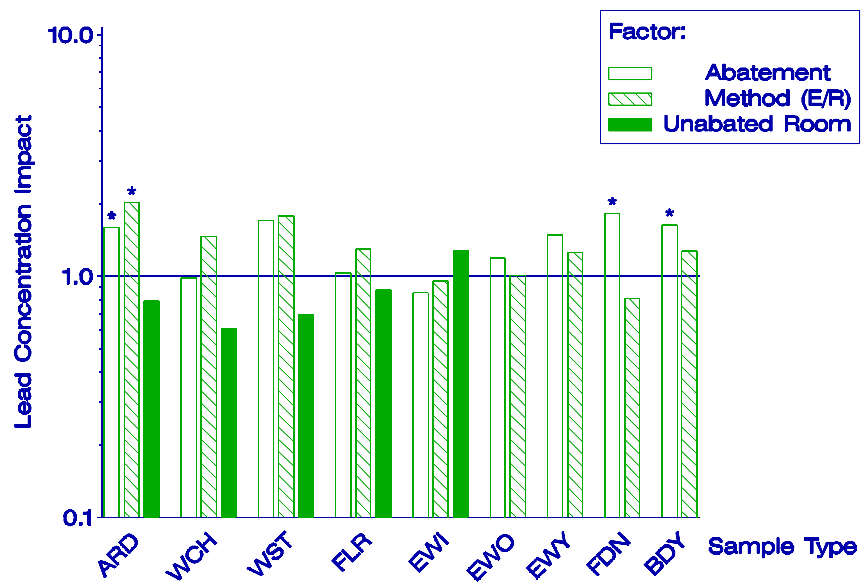

Figure 1-2. Estimated multiplicative effects of abatement from mixed model ANOVA: Lead Concentration

* Bars with a '*' indicate that the factor was statistically significant at the 5 percent level.

bated houses than in unabated houses. Lead loadings were on average 4.7 times greater in the abated homes, reflecting that ducts in the abated houses were also dustier than in unabated houses. On average, lead concentrations in soil were 82 percent greater at the foundation and 63 percent greater at the boundary of abated houses. The difference between the percentage estimates was statistically significant, reflecting a greater contrast between levels at abated and unabated houses in foundation soil than in boundary soil. This suggests that the contrasts between abated and unabated houses is, at least in part, due to lead-based paint. However, it is important to note that air ducts and soil were not abated in the HUD Demonstration. Also, abated houses in this study were 17 years older than unabated houses.

Comparison of Levels in Unabated and Abated Rooms of Abated Homes

To determine whether levels in abated houses varied systematically between abated and unabated rooms, dust samples were collected from floors, window stools, and window channels in both types of rooms, and the following results were found.

> ***Abated vs. Unabated Rooms.*** Lead levels were not significantly different between unabated rooms of abated houses and abated rooms of those same houses.

The seventh column in Table 1-5 lists the estimated multiplicative factor by which geometric mean lead levels in unabated rooms were lower (or higher) than geometric mean lead levels in abated rooms. No differences were statistically significant, although on floors and window channels lead loadings were somewhat lower in unabated rooms (with p values between 0.05 and 0.10).

Comparison of Abatement Methods

In addition to general assessments of abatement efficacy, measures were taken to assess different methods of abatement.

> ***E/E vs. Removal.*** Only in air ducts were mean lead levels significantly higher in houses abated by encapsulation/ enclosure methods than in houses abated by removal methods.

Lead loadings and lead concentrations were significantly higher in the air ducts of E/E houses than in removal houses. Two facts are important to note here. First, houses at which E/E methods were used generally had more lead-based paint present than houses at which removal methods were used. Second, air ducts, which were the only sample type for which significant differences were found with respect to E/E versus removal were not abated in the HUD Demonstration.

Floor lead loadings were on average twice as large in E/E houses as they were in removal houses. This was very nearly statistically significant (p=0.053), suggesting a difference worth recognizing. Noting that the difference in lead concentrations between abated and unabated houses was not signifcant, it is evident that the difference in lead loading is due primarily to increased dust loading in the abated houses.

In addition to sampling and analysis, at the time of sampling each abated substrate in a room or exterior area selected for sampling was visually inspected. Its condition was recorded as either completely (70 percent or more) intact, partially (50 to 70 percent) intact, or minimally (less than 50 percent) intact. Table 1-6 displays a summary of this data by method of abatement. Specific abatement methods are distinguished within the general E/E and removal categories.

> ***Visual Inspection Results***. At least 70 percent of the substrates abated by enclosure, heat gun, and removal and replacement were completely intact at the time of sampling. Less than 60% of those substrates abated by chemical stripping and encapsulation methods were completely intact.

The components which were removed and completely replaced were in the best condition; 95 percent of these were completely intact. When interpreting these results, it should be noted that

Table 1-6. Condition of Abated Substrates, by Method of Abatement

Category	Method	Completely Intact	Partially Intact	Minimally Intact
E/E	Enclosure	40 (80%)	10 (20%)	0
	Encapsulation	109 (58%)	68 (36%)	10 (6%)
Removal	Chemical Stripping	30 (56%)	18 (33%)	6 (11%)
	Heat Gun	40 (70%)	17 (30%)	0
	Removal & Replacement	38 (95%)	2 (5%)	0

the abated houses were unoccupied at the time of abatement, and were not continuously occupied between the completion of abatement and the time of CAP Study sampling. Lack of temperature control and lack of regular cleaning may have more strongly affected the encapsulation or chemical stripping methods than the other abatement methods. Unoccupied houses may not have been heated in the winter, causing temperature swings which could lead to cracking or peeling.

With regard to interpreting all of the modeling results in this section, the reader should be aware of the large number of statistical tests involved in an analysis of this sort. Two or three primary abatement effects were estimated for each sample type listed in Table 1-5. This represents a total of 41 tests at the 5 percent significance level. If all these tests were independent, even if there were no true effects, one would expect about two effects to be identified as significant (41(0.05)=2.05). In fact, the tests are not independent. Concentration measurements are very much related to loading measurements. The exact impact of this dependence is impossible to quantify, however this relationship effectively reduces the actual number of tests being performed. In total, six of the 41 tests produced significant results.

1.3.2 <u>Characterization of Lead Levels</u>

The second objective of the CAP Study was to characterize lead levels in household dust and exterior soil for abated and unabated houses. The following three subsections present these levels, and compare them with interim clearance standards, as well as with results observed in other studies.

<u>Descriptive Statistics</u>

Table 1-7 presents a summary of descriptive statistics associated with the CAP Study. In addition to the geometric mean and the arithmetic mean, the minimum and maximum values are listed with the log standard deviation. The sample sizes in this table are sometimes greater than those presented in Table 1-5. This is because the results presented in the earlier tables controlled for various significant covariates. In cases where the significant covariates were unknown, samples were excluded from fitting the models. The results in Table 1-7 should be given less weight in interpreting the data, because they do not control for factors found to be significant. However, they are useful for comparing the CAP Study with other studies where covariates were not controlled in the reporting of results.

Lead levels were found to vary greatly for different media and sampling locations. Minimum individual lead concentrations for most sample types were usually on the order of 10 µg/g except in air ducts and window channels where levels were at least 50 µg/g. Maximum individual lead concentrations were lowest for boundary and entryway soil samples (1073 and 1068 µg/g, respectively) and highest for window stool and window channel dust samples (48,272 and 45,229 µg/g, respectively). Minimum individual lead loadings for sample types were in general only 1 to 4 µg/ft^2 with window channels being the only exception. Maximum individual lead loadings were lowest for floor dust samples (334 µg/ft^2 by wipe and 11,641 µg/ft^2 by vacuum) and highest for window channel dust samples (244,581 µg/ft^2).

Table 1-7. Descriptive Statistics for Lead Loading (µg/ft^2), Lead Concentration (µg/g), and Dust Loading (mg/ft^2) by Sample Type

Medium	Measurement	Statistic	Air Duct (Vacuum)	Window Channel (Vacuum)	Window Stool (Vacuum)	Floor (Wipe)	Floor (Vacuum)	Entryway Interior (Vacuum)	Entryway Exterior (Vacuum)
Dust	Lead Loading (µg/ft^2)	Number of Samples	109	98	113	67	238	100	97
		Geometric Mean	120.36	2515.59	74.43	11.24	27.15	208.00	384.17
		Arithmetic Mean	1530.60	13637.20	584.62	22.68	244.22	774.18	1234.56
		LN Standard Deviation	2.29	2.24	2.12	1.05	2.03	1.99	1.74
		Minimum	1.85	19.12	0.86	2.72	0.34	1.23	3.97
		Maximum	40863.60	244581.21	16710.45	333.56	11641.25	7349.00	14021.00
	Lead Concentration (µg/g)	Number of Samples	109	98	113		238	100	97
		Geometric Mean	427.19	1438.61	622.94		150.31	186.25	237.48
		Arithmetic Mean	664.07	4920.84	2168.84		395.92	344.97	542.39
		LN Standard Deviation	0.91	1.69	1.55		1.14	1.01	1.06
		Minimum	58.48	72.90	10.15		1.71	9.24	8.84
		Maximum	5644.54	45229.26	48271.93		13567.76	5332.00	16335.45
	Dust Loading (mg/ft^2)	Number of Samples	109	98	113		238	100	97
		Geometric Mean	281.75	1748.63	119.48		180.60	1116.70	1617.67
		Arithmetic Mean	3554.57	4386.95	244.15		572.17	2891.59	3143.55
		LN Standard Deviation	2.00	1.46	1.18		1.65	1.66	1.30
		Minimum	5.01	4.80	4.63		0.43	8.50	40.60
		Maximum	128646.00	46328.75	2824.00		14426.00	20857.40	22170.30
			Entryway	Foundation	Boundary				

Modeling Results

The lead loadings and lead concentrations from the CAP Study models were summarized in Table 1-5, as well as in the following points:

> ***Lead Loadings.*** Geometric mean dust lead loadings in unabated houses varied from a low of 16 μg/ft^2 for floor vacuum dust samples to a high of 1604 μg/ft^2 for window channel samples.
>
> ***Lead Concentrations.*** Geometric mean lead concentrations varied in unabated houses from lows of 86 μg/g for boundary and foundation soil samples and 137 μg/g for floor vacuum dust samples to a high of 851 μg/g for window channel dust samples.

Results from modeling geometric mean lead loadings by housing category are provided in Table 1-8 for floor, window stool, and window channel samples based on an estimation procedure outlined in Section 3 (EPA, 1995b). This procedure uses the ratio estimates presented in columns 4, 5, and 6 of Table 1-5, along with exponents reflecting typical proportions abated by each method.

Table 1-8. Modeled Geometric Mean Lead Loadings by House Type for Floor, Window Stool, and Window Channels (μg/ft^2)

Sample Type	Unabated	Abated	Removal	E/E
Floor	16.2	28.5	17.3	35.0
Window Stool	38.1	70.1	36.5	91.7
Window Channel	1604	1379	2134	1152

Comparisons with HUD and EPA Standards

In addition to comparing relative lead levels among unabated, E/E, and removal houses, these levels in each housing category can be compared against "Lead-Based Paint: Interim Guidelines for Hazard Identification and Abatement in Public and Indian Housing" (HUD, 1990b) abatement clearance standards. These standards for floor, window stool, and window channel dust samples are 200, 500, and 800 $\mu g/ft^2$. The EPA has proposed a reduced standard of 100 $\mu g/ft^2$ for floors, maintaining the 500 ug/ft^2 and 800 $\mu g/ft^2$ standards for window stools and window channels, respectively (EPA, 1994). Geometric mean floor vacuum lead loadings for unabated houses, abated houses, E/E houses, and removal houses were all well below the EPA standard of 100 $\mu g/ft^2$. Similarly, geometric mean window stool lead loadings for these four classes of houses were well below the HUD/EPA standard of 500 $\mu g/ft^2$. In addition, for both of these sample types, more than 75 percent of the samples collected in the CAP Study had lead loadings below their respective standards, in both abated and unabated houses. However, geometric mean window channel lead loadings at both abated and unabated houses were found to be well above the HUD/EPA interim standard of 800 $\mu g/ft^2$, and well over half of individual observations were above this standard, at both abated and unabated houses. It is interesting to note that modeled window channel lead loadings in typical abated houses were actually lower than those for the unabated houses; and that lead loadings were lower in houses abated by encapsulation/ enclosure methods than in houses abated by removal methods. However, the variability in both of these measures prevented either of these differences from being declared statistically significant.

Comparisons with Other Studies

Lead levels observed in the CAP Study were usually equivalent to, or below, levels observed in several other studies, with one notable exception being the HUD National

Survey. Table 1-9 presents lead loadings in floor, window stool, and window channel samples for the CAP Study and four other studies. Along with the geometric mean lead loadings, these

Table 1-9. Descriptive Statistics for Lead Levels Observed in Various Field Studies

Sample Type	Study		House Type	Sample Size	25%	Geom. Mean	75%
Floor lead loading ($\mu g/ft^2$)	CAPS		Unabated Abated	51 187	5.71 6.73	21.38 28.97	64.99 104.34
	HUD Demonstration[1]			1026	23.55	66.01	185.06
	National Survey		High XRF[2] Low XRF[3]	686 90	0.42 0.16	1.47 0.47	5.13 1.41
	Kennedy-Kreiger[4]	Pre-Abatement Post-Abatement Post (6 months)	Traditional Abatement Modified Abatement Traditional Abatement Modified Abatement Traditional Abatement Modified Abatement	280 82 271 50 234 57	na na na na na na	250.84 288.00 1440.00 650.32 315.87 315.87	na na na na na na
	Kennedy-Kreiger[5]	Pre-Abatement Post-Abatement Post (6 months)		70 70 63	na na na	520.26 130.06 55.74	na na na
Window stool lead loading ($\mu g/ft^2$)	CAPS		Unabated Abated	35 78	9.85 15.43	46.90 91.57	224.68 467.23
	HUD Demonstration[1]			783	26.70	89.06	297.09
	National Survey		High XRF[2] Low XRF[3]	329 38	0.82 0.24	4.32 1.26	22.77 6.68
	Kennedy-Kreiger[4]	Pre-Abatement Post-Abatement Post (6 months)	Traditional Abatement Modified Abatement Traditional Abatement Modified Abatement Traditional Abatement Modified Abatement	280 82 271 50 234 57	na na na na na na	1337.80 1802.32 3595.35 603.87 1542.19 1635.09	na na na na na na
	Kennedy-Kreiger[5]	Pre-Abatement Post-Abatement Post (6 months)		70 70 63	na na na	4607.99 325.16 408.77	na na na
Window channel lead loading ($\mu g/ft^2$)	CAPS		Unabated Abated	27 71	738.00 510.51	2330.21 2589.90	12427.41 18883.56
	HUD Demonstration[1]			756	138.10	506.21	1855.57
	National Survey		High XRF[2] Low XRF[3]	142 7	12.08 2.97	72.64 28.94	436.72 282.33
	Kennedy-Kreiger[4]	Pre-Abatement Post-Abatement Post (6 months)	Traditional Abatement Modified Abatement Traditional Abatement Modified Abatement Traditional Abatement Modified Abatement	280 82 271 50 234 57	na na na na na na	15496.2 2 18274.0 314353. 52 8082.56 12467.5 9 24879.4 3	na na na na na na
	Kennedy-Kreiger[5]	Pre-Abatement Post-Abatement Post (6 months)		70 70 63	na na na	29422.3 9 938.32 1003.35	na na na

(1) All metropolitan areas in the FHA portion.
(2) Predicted maximum interior or exterior XRF reading at these residences was at least 1.0 mg/cm^2.
(3) Predicted maximum XRF reading at these residences was below 1.0 mg/cm^2.
(4) Farfel and Chisolm (1990).
(5) Farfel and Chisolm (1991).

tables also present the 25th and 75th percentile lead loadings when they were available. The following main conclusion can be made from this table:

> ***Comparison with Other Studies.*** CAP Study lead loadings were at or below those in the other studies, with three exceptions. First, the CAP Study geometric mean window channel lead loadings (approximately 2500 µg/ft^2) were significantly higher than those recorded for the HUD Demonstration Study (approximately 500 µg/ft^2). Second, for floor, window stool, and window channel samples, the CAP Study geometric mean lead levels were typically at least an order of magnitude higher than for National Survey samples. Third, CAP Study geometric mean lead loadings for window channels were approximately twice as high as post-abatement levels in the second Kennedy-Krieger Study.

The greater observed window channel lead loadings might be due to the fact that the CAP Study sampled only in Denver, while the HUD Demonstration Study sampled in Denver and six other metropolitan areas. The difference might also be due to increased sample recovery achieved in the CAP Study using cyclone vacuum sampling as opposed to the HUD Demonstration Study wipe sampling. Also, it may be that lead re-accumulated from sources, such as soil and air ducts, in the period between abatement and sampling, or that CAP Study houses were dustier due to differences in cleaning practices.

The second case in which CAP Study lead loadings were relatively high was in comparison with HUD National Survey results. For floor, window stool, and window channel samples, the CAP Study lead levels were typically at least an order of magnitude higher than for National Survey samples. Some of these differences are accounted for by low sample recoveries obtained in the HUD National Survey. Vacuum versus wipe field testing by

EPA (EPA, 1995a) indicated that the vacuum sampling protocol used in the HUD National Survey recovered only about 20% of the lead dust that would be recovered by a wipe sample. Wipe sample results tended to be less than or equivalent to those from the CAPS vacuum sampler. Hence there is likely to be at least a five fold difference between CAPS vacuum dust results and National Survey vacuum dust results, which would account for some of the differences in lead loadings between the CAP Study and the National Survey.

1.3.3 Correlation of Lead Levels in Different Media and Locations

The third objective of the CAP Study was to investigate the relationship between lead levels in different media (i.e., dust and soil) and different sampling locations (e.g., floors, window channels, foundation soil). These relationships were quantified by between-house and within-house correlation coefficients. Between-house correlations reflect house-to-house relationships among different sample types, such as between air ducts and window channels. Within-house correlations are similar measures, except they are based on room-to-room differences within a house, after controlling for house average lead levels. For some pairs of sample types (e.g., entryway interior and floor vacuum), there were insufficient data available to estimate the within-house correlations after fitting the statistical model. Correlation coefficients were calculated for both lead loadings and lead concentrations. However, only a relatively small number of correlation coefficients were found to be significant. The significant relationships found are presented in Table 1-10 and summarized in the following points:

Between-House Correlations for Lead Loadings. At the house level, significant correlations in dust lead loadings were found for three pairs of sample types. These were between window channels and window stools (correlation coefficient of 0.56), between air ducts and exterior entryways (0.41), and between floor (wipe) samples and exterior entryways (0.44).

Between-House Correlations for Lead Concentrations. Significant correlations in lead concentrations at the house level were found for four pairs of sample types. These were between lead concentrations in window channel and window stool dust (0.40), between entryway soil and boundary soil (0.56), between boundary soil and window stool dust (0.38) and between entryway soil and interior entryway dust (0.29).

Table 1-10. Significant Between-House and Within-House Correlations

Response	Correlated Sample Types	Correlation	DF*	Significance
Between-House Lead Loading	Air duct and exterior entryway dust	0.41	36	.01
	Window channel and window stool	0.56	41	<.01
	Floor (wipe) and exterior entryway dust	0.44	27	.02
Between-House Lead Concentration	Window channel and window stool	0.40	41	.01
	Window stool and boundary soil	0.38	44	.01
	Interior entryway and entryway soil	0.29	44	.05
	Entryway soil and boundary soil	0.56	44	<.01
Within-House Lead Loading	No significant correlations	-	-	-
Within-House Lead Concentration	Interior entryway and exterior entryway dust	0.37	31	0.03

Within-House Correlations. At the room level, no significant correlations in dust lead loadings were found. However, significant correlation was observed between interior and exterior entryway dust lead concentrations (0.37).

The reader should note that there were a total of 50 correlation tests performed. With a 5 percent significance level, one could expect about two to three significant relationships simply by chance. A total of eight significant correlations were identified.

This column lists the degrees of freedom available to estimate correlation after controlling for significant model factors.

1.3.4 Comparison of Cyclone and Wipe Dust Sampling

A final objective of the CAP Study, which was not originally stated at the study design stage but which evolved during the course of the study, was to compare the performance of two dust sampling protocols: cyclone vacuum sampling and wipe sampling. The results of this comparison are presented in Table 1-11, and can be summarized as follows:

> ***Vacuum vs. Wipe Ignoring Substrate.*** Lead loadings from side-by-side wipe and (cyclone) vacuum dust samples were not significantly different when pooled across the various substrates sampled in the CAP Study.
>
> ***Vacuum vs. Wipe by Substrate.*** The performance of these two sampling protocols was found to be different for different substrates. On tile and linoleum surfaces cyclone vacuum lead loadings were not found to be significantly different from wipe lead loadings. Cyclone lead loadings were higher than wipe lead loadings on wood surfaces (3.9 times higher). The 95% confidence interval for the ratio of vacuum to wipe recovery on wood was 1.13 to 13.59.

Table 1-11. Vacuum/Wipe Multiplicative Bias Estimates

Substrate	Sets of Observations	Estimated Vacuum/Wipe Multiplicative Bias	Lower Confidence Bound	Upper Confidence Bound
Tile	5	0.69	0.12	3.90
Linoleum	18	1.02	0.42	2.44
Wood	9	3.92	1.13	13.59
Combined	33	1.38	0.75	2.54

1.3.5 Results of the Quality Control and Data Verification Procedures

Results of the quality control (QC) procedures confirmed that the sampling and analytical protocols employed in the CAP Study produced data of sufficient quality. Analysis of the blank samples suggested little if any procedural contamination. The majority of blanks were measured with a lead content below the instrumental level of detection. Despite some procedural problems in their creation and analysis, the results for the recovery samples indicated very good method performance. Spiked duplicate samples created in the laboratory exhibited very good agreement. Finally, there was no significant evidence of a time-based trend in any of the QC samples.

Additional data verification procedures included a laboratory review of potential outliers statistically identified in the data, an audit of the data management system, and a laboratory quality assurance audit. The results of these procedures further verified the accuracy of the data upon which the analyses were based. Moreover, a statistical analysis audit confirmed that the reported statistical analyses were correctly performed.

The inherent variability between field samples, however, was evident in the results of the side-by-side field samples. Despite being collected side-by-side, a number of the pairs were measured to have very different lead contents. Greater inherent variation was seen in dust samples than in soil samples. The median ratio of the larger to the smaller of two side-by-side vacuum dust lead loadings in the CAP Study was about 2.33. The median ratio for lead concentrations was 2.07. These results suggest that studies to assess abatement performance and potential lead hazards must be carefully designed to control for these complicating sampling variations. For example, random selection of sampling locations was incorporated into the CAP Study design to eliminate biases in sample selection.

1.4 **DISCUSSION**

The CAP Study demonstrated that an accurate assessment of potential lead hazards can be seriously complicated by the high degree of variability commonly found in environmental lead measures. Lead determinations can depend heavily on the sampling and analysis procedures used, and they can vary greatly among similar housing environments and among different sampling locations within a single housing environment.

Pre- Vs. Post-Abatement Lead Levels

The CAP Study included two approaches for assessing abatement efficacy, one direct approach and one indirect approach. The results of the CAP Study from the direct approach of comparing post-abatement and pre-abatement lead levels were that for the two sample types for which a comparison was possible, abatement appears to have been effective, in the sense that there is no evidence that post-abatement lead levels were significantly higher than pre-abatement levels. This result is based on dust lead measurements made on window stools at 10 CAP Study abated houses, as well as soil lead measurements made at 24 CAP Study abated houses. Several floor dust samples were also available for comparison, but were deemed insufficient for making substantive conclusions.

These results indicate that while the abatements may not have reduced lead levels in dust and soil from their pre-abatement condition, the abatements were successfully performed without raising lead levels in these two media. This finding is significant since the pre-abatement lead levels in dust and soil were already relatively low in comparison with levels found by other field studies. However, these results are tempered by the fact that because of the small number of houses for which data were available, as well as the large variability in observed lead levels, relatively large differences between post-abatement and pre-abatement lead levels could not be judged to be statistically significant. For example, the confidence interval about an average ratio of post-abatement to pre-abatement levels on window stools was 0.37 to 3.46, indicating that three-fold differences would be judged insignificant. In addition, further complicating the comparison of post-abatement and pre-abatement dust and soil lead measurements was the fact that different sampling and analysis protocols were used in the CAP Study and HUD Demonstration. Perhaps most significantly, the CAP Study utilized vacuum dust sampling while the HUD Demonstration utilized wipe dust sampling.

Lead Levels in Abated vs. Unabated Houses

The indirect assessment of abatement efficacy also found that abatement appears to have been effective, in this case in the sense that there is no evidence that post-abatement lead levels at abated houses were significantly different from lead levels at neighboring unabated houses found to be relatively free of lead-based paint. There were two exceptions to this statement; however, both of these exceptions were anticipated and are logically explained. First, lead concentrations in air ducts were significantly higher in abated houses than in unabated houses; air ducts were not abated in the HUD Demonstration. In addition, lead concentrations in the soil outside abated houses were significantly higher at the foundation and at the boundary than corresponding lead concentrations outside unabated houses. This difference between soil lead concentrations at abated and unabated houses was significantly more pronounced near the foundation than it was at the boundary. This suggests that these contrasts are due at least in part to lead-based paint at the abated houses. However, soil also was not abated during the HUD Demonstration; and these higher lead levels might in part be due to differences in the age of these houses, since on average the abated houses in this study were 17 years older than unabated houses. As with the caveat stated above, these results must also be tempered by the fact that not finding a significant difference in lead levels at abated and unabated houses for all other building components and sampling locations does not prove that no such differences exist. The CAP Study was designed to detect approximately two-fold differences between lead levels at abated and unabated houses under specified variance assumptions. For example, although the estimate of 1.76 for the ratio of lead loadings on floors in abated to unabated houses was not significantly different from one, the 95 percent confidence interval was from about 0.87 to 3.5.

Comparison of Abatement Methods

The CAP Study also assessed abatement by comparing encapsulation and enclosure methods versus removal methods. No significant differences among lead levels could be attributed to these two types of abatement methods, except for air ducts which, as stated above, were not abated. Air duct dust lead levels were higher in houses abated primarily by encapsulation and enclosure methods than in houses abated primarily by removal methods. The CAP Study also performed a visual inspection of abated surfaces and recorded their condition as being completely intact, partially intact, or minimally intact. Less than 60% of the surfaces abated by encapsulation and chemical stripping methods were found to be completely intact, while more than 70% of the surfaces abated by all other methods were found completely intact.

These results suggest that both encapsulation/enclosure and removal abatement methods can be performed in residential housing environments without depositing significant amounts of residual lead in dust and soil. Of course, proper dust control procedures must be employed while conducting any lead-based paint hazard abatement. However, while dust and soil lead levels were not found to be significantly different two years after abatement, there is some indication from the visual inspection information that residual problems may be seen in the future at locations abated with encapsulation and chemical stripping methods.

Characterization of Lead Levels

With regard to the second study objective, lead levels were found to vary greatly for different media and sampling locations. Dust lead loadings were also evaluated in comparison with the HUD and EPA interim dust clearance standards. Geometric mean floor lead loadings at both abated and unabated houses were below the EPA standard of 100 µg/ft^2. Geometric mean window stool lead loadings were found to be below the HUD/EPA interim standard of 500 µg/ft^2. In addition, for window stools in both abated and unabated houses, and for floors in unabated houses, more than 75 percent of the samples collected in the CAP Study had lead loadings below their respective standards, in both abated and unabated houses. The 75th percentile of floor lead loadings in abated houses was about 104 µg/ft^2. However, geometric mean window channel lead loadings at both abated and unabated houses were found to be well above the HUD interim standard of 800 µg/ft^2, and well over half of individual observations were above this standard, at both abated and unabated houses.

Most of the samples in the CAP Study were collected by a vacuum method of dust collection. Clearance samples are usually collected by a wipe method. In the CAP Study comparison of vacuum and wipe methods, wipes tended to produce either equivalent or lower lead levels than the vacuum used in the CAP Study, with the most pronounced difference on wood substrates. The CAP Study vacuum samples resulted in geometric mean lead loadings that were less than the clearance standards for floors and window stools. From the relationship between wipe and vacuum samples demonstrated in the CAP Study, it is plausible to infer that wipe samples would also produce geometric mean lead loadings less than the clearance standards for floors and window stools. However, for window channels, the CAP vacuum samples were generally above the clearance standard. Because of the difference between vacuum and wipe samples, especially on wood, it is not clear that wipe samples on window channels would exceed the clearance standard.

Overall Assessment of Abatement

The CAP Study found no significant differences between post-abatement and pre-abatement lead levels for exterior soil and the limited number of window stool dust lead measurements available. It also found no significant differences between post-abatement lead levels at abated houses and lead levels at unabated houses, with the exception of air duct dust and soil which were not abated in the HUD Demonstration. In addition, for both floors and window stools the geometric mean lead loadings at abated houses were well below the HUD standards of 200 and 500 $\mu g/ft^2$. These results all suggest that the HUD abatement activities were effective, in the sense that they do not appear to have increased lead levels at abated houses above interim standards. However, the CAP Study also found that the geometric mean lead loading for window channels at abated houses was well above the HUD interim standard of 800 $\mu g/ft^2$, although the same result was found for unabated houses relatively free of lead-based paint.

Correlations Among Media and Sampling Locations

Three primary conclusions were found for the third CAP Study objective. First, significant correlations in lead concentrations at the house level were found for four pairs of sample types: window channels and window stools (correlation coefficient of 0.40), entryway soil and boundary soil (0.56), boundary soil and window stools (0.38), and entryway soil and interior entryway dust (0.29). Second, at the house level, significant correlations in dust lead loadings were found for three pairs of sample types: window channels and window stools (0.56), air ducts and exterior entryway dust (0.41), and floor (wipe) dust and exterior entryway dust (0.44). And third, at the room level, no significant correlations in dust lead loadings were found. However, significant correlation was observed between dust lead concentrations at interior and exterior entryways (0.37). House level correlations were based on house averages; room level correlations were based in most cases on single measurements.

The fact that significant correlations were found in the CAP Study suggests that lead may be redistributed over time throughout a residential housing environment. However, the fact that more house-level correlations were significant suggests that overall lead levels are more related to broad differences among houses than to location-specific characteristics within houses.

Cyclone Vacuum vs. Wipe Dust Sampling

Combined across substrates, the difference between dust lead loadings measured by the cyclone vacuum method and by the wipe method was not significant. Differences were overshadowed both by large side-by-side variability in the two methods, and a strong substrate effect. This latter effect was apparently related to the smoothness of the substrate. On tile and linoleum, the two methods were approximately equivalent, whereas on wood lead loadings measured by the cyclone were higher than those measured by wipe. Thus, the level of lead measured depends on the way in which it is collected. This study has led to several subsequent investigations of dust collection methods, including the Rochester Study of the relationship between different dust collection methods and children's blood lead levels, and an EPA laboratory study of different dust collection methods.

Future Research

Several research issues have been raised but not addressed by the CAP Study. The two main issues are discussed in this section.

There has been no direct assessment of the relationship between health risks and the environmental sampling being performed in the CAP Study. In the CAP Study, an implicit assumption was made that health risks are correlated with dust and soil lead levels at residences. No blood or other health-based observations were made at the houses sampled in the CAP Study, precluding the assessment of abatement efficacy with respect to the prevention of health risks.

The methods used for abatement in the CAP Study were generally expensive. Removal and enclosure methods can be particularly costly. Other less costly approaches to abatement such as regular wet mopping, dust cleaning, paint stabilization, and in-home education deserve consideration and study.

Other ongoing studies are investigating the efficacy of less costly means of abatement. These include a dust cleaning products study, the Repair and Maintenance Study in Baltimore, the Milwaukee Low-Cost Efficacy Study, and additional low-cost abatement studies in other cities co-funded by EPA and the Centers for Disease Control and Prevention.

2.0 DESCRIPTIVE STATISTICS

As noted in the previous chapter, nine regular types of samples were collected at each housing unit in this study (see Table 1-3). Vacuum dust samples were collected from air ducts, interior and exterior entryways, floors, window stools, and window channels within each house. Soil core samples were obtained at the boundary of the property, the foundation of the house, and an entryway to the house. In addition to these nine sample types, wipe dust samples were also collected from floors for purposes of comparison with vacuum sampling results. In the analyses that follow, abbreviations are used to identify these various sample types. The abbreviations were displayed above in Table 1-4.

2.1 DUST COLLECTED

When interpreting results of vacuum dust sampling in a residential setting, information about the amount of dust collected is important. Lead concentrations can not be calculated without measurements of the amount of dust collected. Lead loadings are jointly determined by the lead concentration and the dust loading. And, the detection limit for dust lead concentration is a direct function of the amount of dust collected. In Table 2-1, descriptive statistics are reported by sample type for the amount of dust collected (mg) by the vacuum sampling method. The statistics presented are the number of samples, geometric mean, logarithmic standard deviation, minimum, and maximum. The amount of dust by sample type is illustrated graphically in Figure 2-1. In this figure, box and whisker plots display on a logarithmic scale the amount of dust collected by sample type. Note that the axis' minor tick marks are not uniformly distributed between the major tick marks.

Table 2-1. Descriptive Statistics for Amount of Dust Collected (mg) and Area Sampled (ft^2) by Sample Type

Statistic	Air Duct (Vacuum) [ARD]	Window Channel (Vacuum) [WCH]	Window Stool (Vacuum) [WST]	Floor (Wipe) [FLW]	Floor (Vacuum) [FLR]	Entryway Interior (Vacuum) [EWI]	Entryway Exterior (Vacuum) [EWO]
Amount of Dust (mg)							
Number of Samples	109	98	113	0	238	100	97
Arithmetic Mean	355.42	1324.36	174.11	.	572.12	2880.35	3081.30
Geometric Mean	95.49	617.08	89.22	.	180.81	1112.18	1583.29
Standard Deviation	1.68	1.43	1.18	.	1.65	1.66	1.30
Minimum	2.20	0.50	2.30	.	40.60	8.50	40.60
Maximum	4215.10	13285.80	2299.40	.	14426.00	20857.40	22170.30
Area Sampled (ft^2)							
Number of Samples	109	98	113	67	238	100	97
Arithmetic Mean	0.43	0.52	0.90	1.00	1.00	1.00	0.98
Standard Deviation	0.26	0.41	0.63	0.01	0.03	0.03	0.07
Minimum	0.03	0.05	0.11	0.96	0.96	0.67	0.50
Maximum	1.44	1.83	4.73	1.00	1.40	1.00	1.00

Box and whisker plots illustrate the center, scatter, and skewness of a dataset. The lower and upper quartiles of the data are represented by the bottom and top of the box, respectively. The distance embodied by the box is termed the interquartile range, the range from the 25th to 75th percentile. The bar within the box portrays the median of the data. The lower and upper tails of the distribution are represented by the whiskers extending from the bottom and top of the box. Extreme data points are classified as either minor (pluses) or extreme (stars) outliers based on their distance from the quartiles relative to the interquartile range. The arithmetic mean amount of dust is displayed as a diamond.

The amount of dust collected by the vacuum sampler was seldom less than 10 mg (the amount targeted by the laboratory chemists in the study plans), and never exceeded 25 grams (25000 mg). The geometric mean amount of dust for each sample type was at least 90 mg. Problems in collecting air duct samples resulted in their surprisingly small amount of dust. The large amount of dust collected from window channels was due to a very high dust

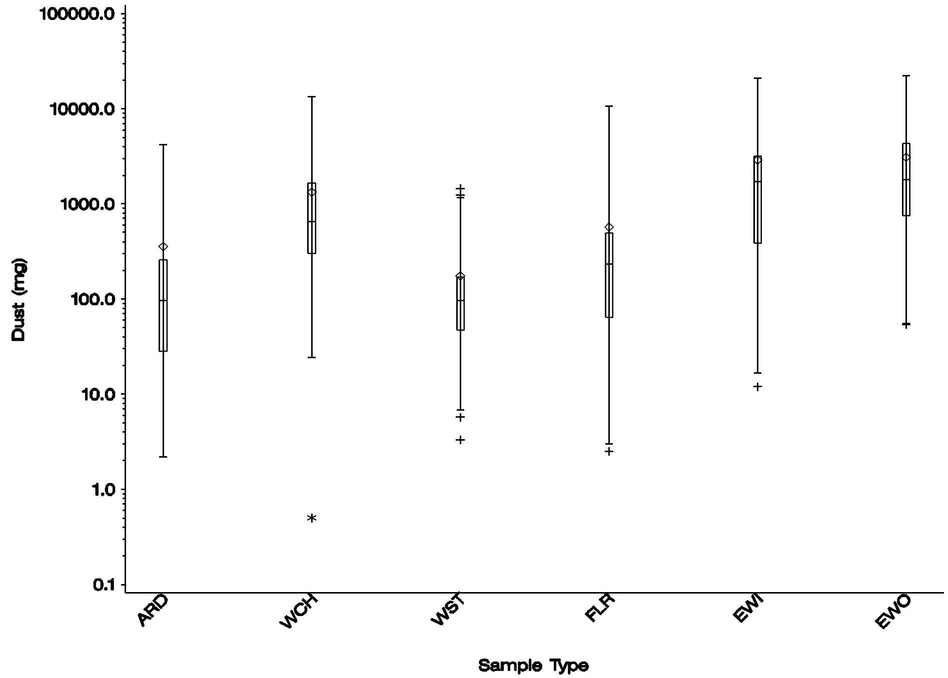

Figure 2-1. Amount of dust collected (mg) by sample type.

Box represents range from 25th to 75th percentile; bar and diamond represent geometric and arithmetic means, respectively; whiskers represent lower and upper tails of the distribution; and extreme data points are classified as either minor (pluses) or extreme (stars).

loading (mg/ft^2) which compensated for the very small area available for sampling (less than for window stool samples).

2.2 AREA SAMPLED

The square footage sampled when collecting vacuum and wipe dust samples is useful for interpreting the resulting lead loadings and concentrations. In Table 2-1, descriptive statistics are reported by sample type for the area sampled (ft^2) by both the vacuum and wipe sampling methods. The number of samples, arithmetic mean, standard deviation, minimum and maximum are reported. These results are illustrated in Figure 2-2 by box and whisker plots of area sampled for each sample type.

With only a few exceptions, one square foot of surface area was sampled when the interior entryway, exterior entryway, floor vacuum, and floor wipe samples were collected. The area sampled during the collection of air duct, window stool and window channel samples, however, varied considerably. In the case of window stools, as little as 0.1 ft^2 to nearly 5 ft^2 were sampled. Since the sampling protocol called for collecting dust from the entire window stool or channel, the variation was mostly a function of differences in the construction of the houses. For example, a window stool in house 44 was 47 inches long and 14.5 inches wide, while a window stool in house 95 was 63.5 inches long and 7.9 inches wide. The average area sampled on air ducts and window channels was approximately 0.4 ft^2 while an average of approximately 0.9 ft^2 was sampled on window stools.

2.3 LEAD LOADING, LEAD CONCENTRATION, AND DUST LOADING

Three measurements were made on the dust and soil samples. They are:

50

Lead Loading: Amount of lead (μg) in household dust per square foot (ft^2) of surface area sampled.

51

Box represents range from 25th to 75th percentile; bar and diamond represent geometric and arithmetic whiskers represent lower and upper tails of the distribution; and extreme data points are classified as eithe extreme (stars).

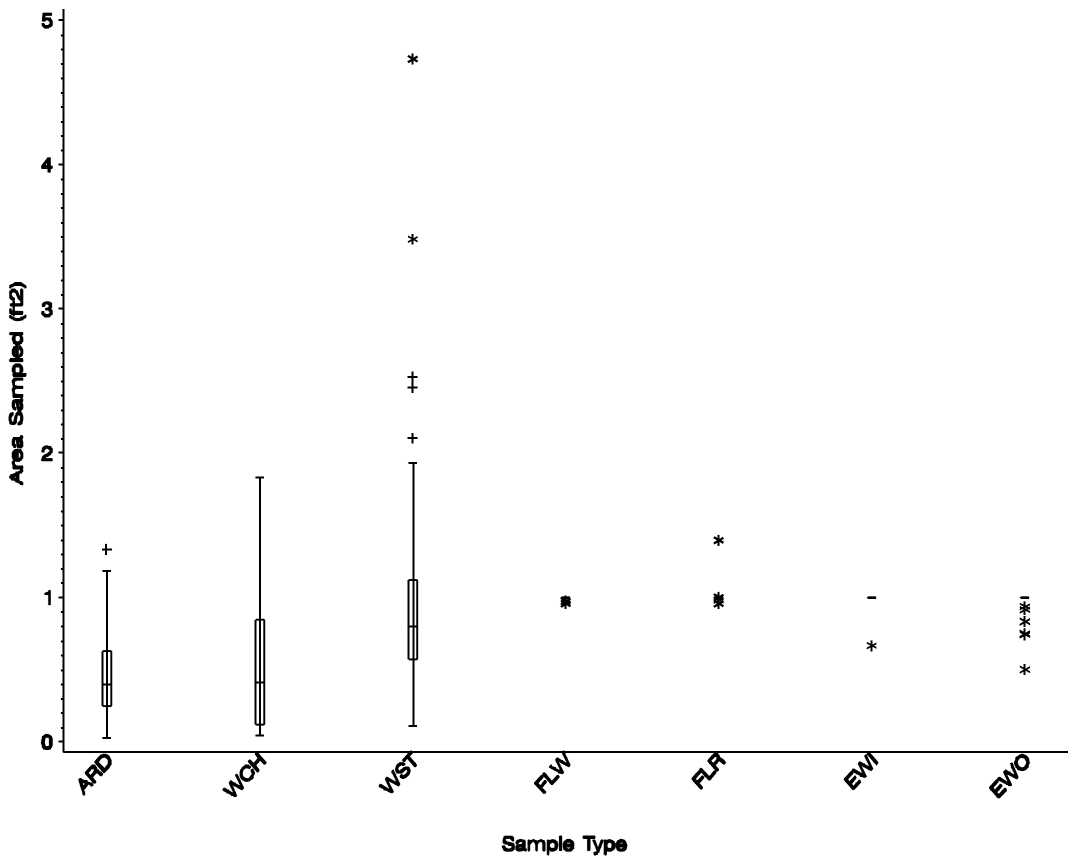

Figure 2-2. Area sampled (ft^2) by sample type.

Box represents range from 25th to 75th percentile; bar and diamond represent geometric and arithmetic means, respectively; whiskers represent lower and upper tails of the distribution; and extreme data points are classified as either minor (pluses) or extreme (stars).

Lead Concentration: Amount of lead (μg) per gram (g) of household dust sampled, or amount of lead (μg) per gram (g) of soil sampled.

Dust Loading: Amount of household dust (mg) per square foot (ft^2) of surface area sampled.

All three measures were obtained for vacuum dust samples. Only lead loading could be measured on wipe dust samples since the amount of dust collected could not be determined due to uncertainty in the weight of individual baby wipes. For soil samples, only lead concentration could be determined because essentially a point, not a surface, was sampled.

Descriptive statistics for all housing units combined were presented above in Table 1-7 by sample type for all three measurement types. The descriptive statistics reported include the number of samples collected, geometric mean, arithmetic mean, logarithmic standard deviation, minimum and maximum. Figure 2-3 displays box and whisker plots for lead loading across all houses plotted versus sample type. Comparable plots for lead concentration and dust loading are presented in Figures 2-4 and 2-5, respectively.

Log-transformed lead loadings, lead concentrations, and dust loadings were used in all of the statistical analyses. Using log-transformed environmental lead measures is common and supported in the literature. Reeves, et al, (Reeves, et al, 1982) found that the normal distribution did not adequately fit their data on lead in paint, soil, and house dust. Further, the data were found to be closer in form to the lognormal distribution than the normal distribution. The data obtained in this CAP Study illustrate another important reason for using log-transformed data; the measurements range over four to five orders of magnitude. In addition, the geometric means are often much closer to the medians than the arithmetic means (illustrated in

Figures 2-3, 2-4 and 2-5). This is evidence that the distributions are more symmetric on a log scale than a linear

Box represents range from 25th to 75th percentile; bar and diamond represent geometric and arithmetic means, respect: upper tails of the distribution; and extreme data points are classified as either minor (pluses) or extreme (stars).

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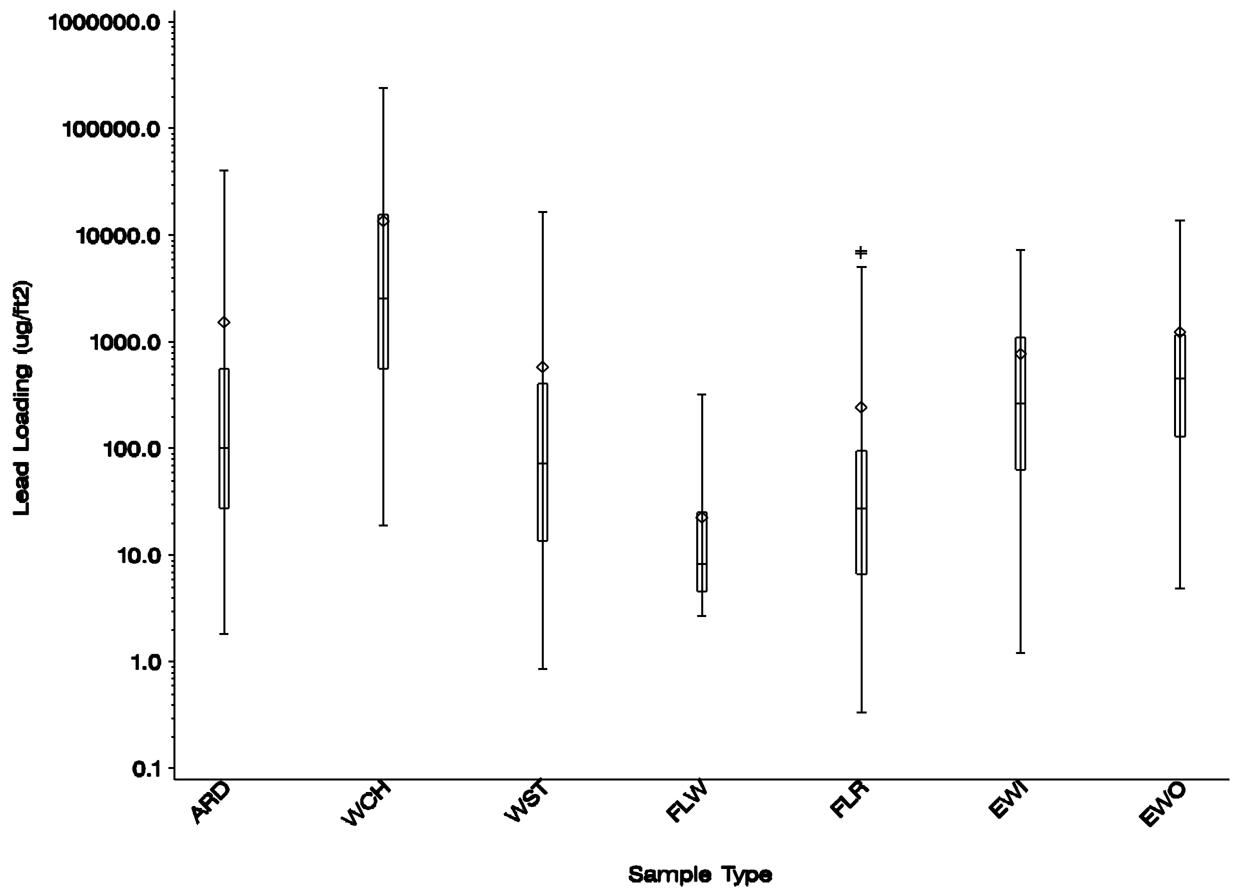


Figure 2-3. Lead loading ($\mu g/ft^2$) by sample type.

Box represents range from 25th to 75th percentile; bar and diamond represent geometric and arithmetic means, respectively; whiskers represent lower and upper tails of the distribution; and extreme data points are classified as either minor (pluses) or extreme (stars).

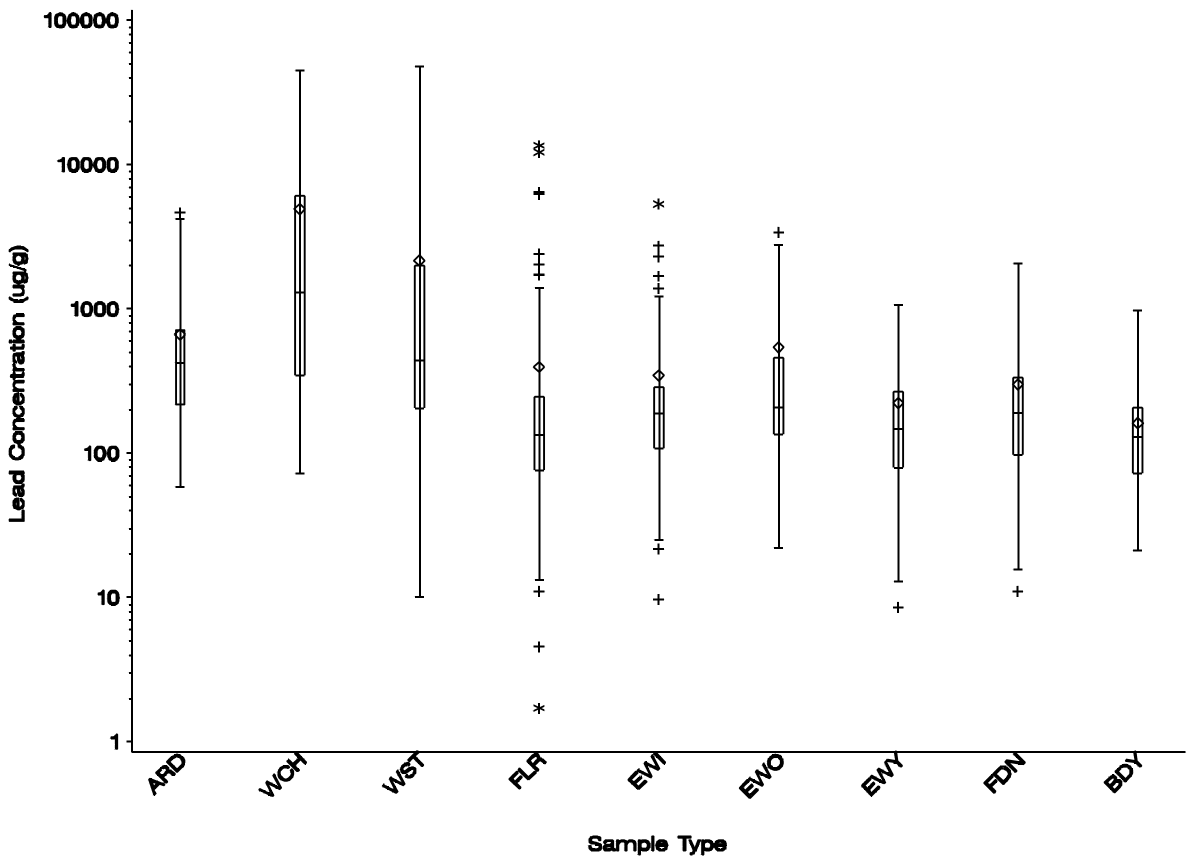


Figure 2-4. Lead concentration (μg/g) by sample type.

Box represents range from 25th to 75th percentile; bar and diamond represent geometric and arithmetic means, respectively; whiskers represent lower and upper tails of the distribution; and extreme data points are classified as either minor (pluses) or extreme (stars).

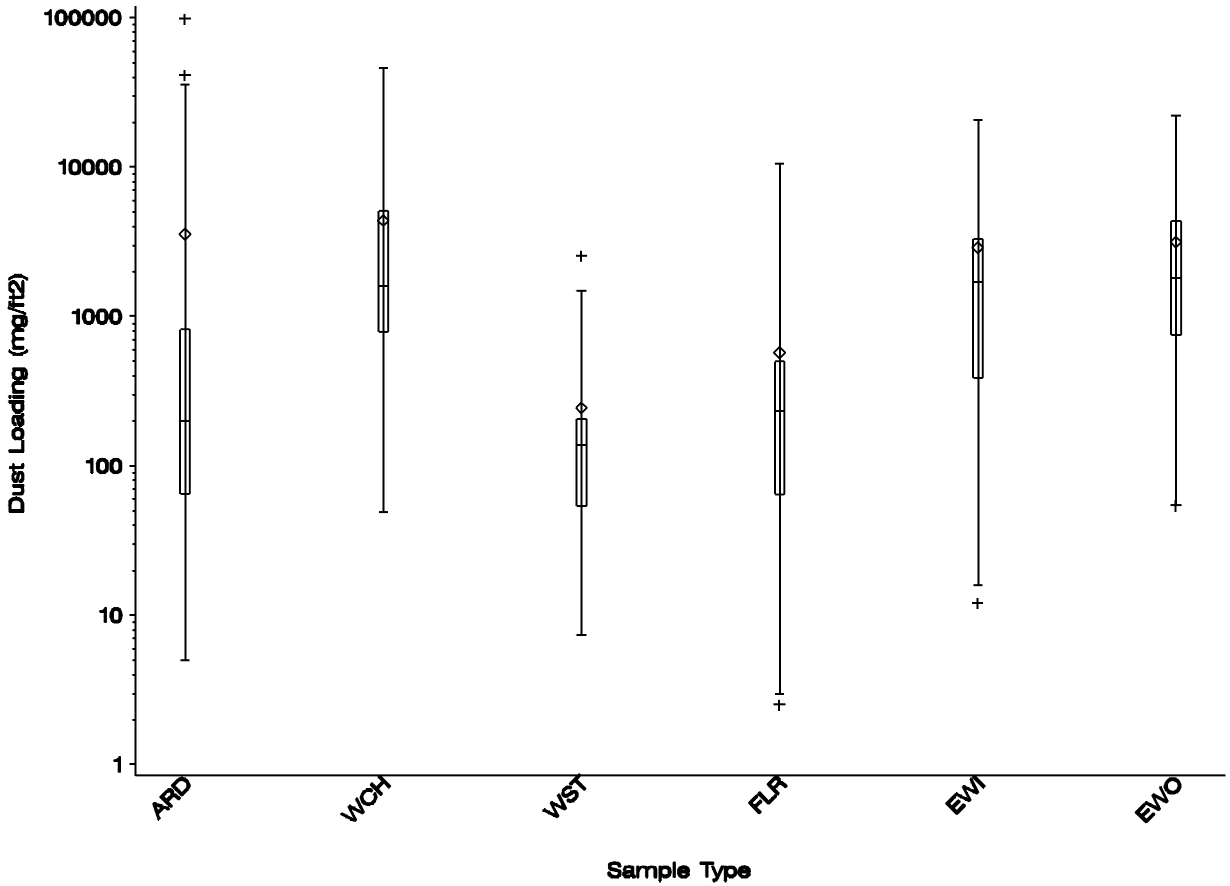


Figure 2-5. Dust loading (mg/ft^2) by sample type.

Box represents range from 25th to 75th percentile; bar and diamond represent geometric and arithmetic means, respectively; whiskers represent lower and upper tails of the distribution; and extreme data points are classified as either minor (pluses) or extreme (stars).

scale, and hence that the lognormal distribution is more appropriate than the normal distribution.

The geometric mean and logarithmic standard deviation are natural summary parameters for lognormally distributed data. The geometric mean is calculated by taking the natural logarithm of the data values, calculating their arithmetic mean, and exponentiating (taking the antilog). The logarithmic standard deviation, in turn, is determined by taking the natural logarithm of the original data and then calculating their standard deviation.

Correlations among lead loadings, lead concentrations, and dust loadings were assessed for the six types of vacuum dust samples collected. Table 2-2 displays the estimated correlations for each type of sample. These estimates are based on the log-transformed data. For all six sample types the estimated correlations between lead loadings and lead concentrations, and lead loadings and dust loadings were significantly different from zero. This is to be expected since lead loading can be calculated as the product of lead concentration times dust loading, divided by 1000. In contrast, the estimated correlations between lead concentrations and dust loadings were not significantly different from zero for any of the sample types. The estimated correlations between lead loadings and dust loadings were higher than those between lead loadings and lead concentrations, except for window stool and channel samples. When the samples were pooled across sample types, all the average correlations were significantly different from zero. The average estimated correlation among lead concentrations and dust loadings (0.12), however, was smaller than those among lead loadings and dust loadings (0.82), and lead loadings and lead concentrations (0.67).

Table 2-2. Correlations of Log Lead Loading Versus Log Lead Concentration for Dust Samples

Sample Type	Number of Samples	Estimated Correlation		
		Pb Load vs Pb Conc	Pb Load vs Dust Load	Pb Conc vs Dust Load
Air Ducts	109	0.50*	0.92*	0.12
Window Channel	98	0.76*	0.66*	0.002
Window Stool	113	0.84*	0.70*	0.19
Floor	238	0.58*	0.83*	0.02
Entryway Interior	100	0.56*	0.86*	0.05
Entryway Exterior	97	0.66*	0.79*	0.07
Across Sample Types	755	0.67*	0.82*	0.12*

* Significant at the 0.01 level.

2.4 CLASSIFICATION OF HOUSES

At least two abatement methods were used for almost every house abated in the HUD Abatement Demonstration. In most cases, both encapsulant/enclosure and removal methods were applied. Table 2-3 displays the interior square footage abated by each of the six method categories used in the demonstration: encapsulation, enclosure, removal, heat gun, chemical stripping, and removal and replacement. Encapsulation/enclosure and removal subtotals and grand total abatement square footage abated are also listed. The arithmetic average and median of each column is listed at the bottom of the table. Table 2-4 displays the same information on exterior abatement. It is clear that there is wide variety in the distribution of methods applied. Recognition of this distribution was necessary in order to characterize differences in abatement performance as it depends on the abatement method applied. Details of the approach used are described in Section 3.0 on statistical models.

Table 2-3. Interior Abatement by Method for Each House (ft^2)

House	Encapsulation/Enclosure			Removal					Total Abated
	Encapsulate	Enclosure	Total E/E	Removal	Heat Gun	Chemical Stripping	Remove/ Replace	Total Removal	
07	257.67	200.00	457.67	0.00	0.00	0.00	0.00	0.00	457.67
09	107.91	0.00	107.91	0.00	0.00	0.00	0.00	0.00	107.91
10	681.60	0.00	681.60	0.00	0.00	26.00	0.00	26.00	707.60
11	146.66	0.00	146.66	0.00	0.00	11.10	0.00	11.10	157.76
17	192.00	0.00	192.00	0.00	0.00	0.00	0.00	0.00	192.00
18	12.00	0.00	12.00	0.00	0.00	0.00	0.00	0.00	12.00
21	0.00	120.00	120.00	0.00	175.41	0.00	68.00	243.41	363.41
24	0.00	0.00	0.00	0.00	0.00	1.00	12.68	13.68	13.68
25	157.00	167.00	324.00	0.00	0.00	0.00	0.00	0.00	324.00
31	21.00	0.00	21.00	0.00	0.00	0.00	0.00	0.00	21.00
39	0.00	1037.00	1037.00	0.00	353.40	54.00	79.00	486.40	1523.40
40	132.99	0.00	132.99	0.00	0.00	0.00	0.00	0.00	132.99
41	1204.99	0.00	1204.99	0.00	0.00	0.00	0.00	0.00	1204.99
44	0.00	0.00	0.00	0.00	20.00	25.00	44.44	89.44	89.44
46	0.50	0.00	0.50	0.00	89.95	0.00	0.00	89.95	90.45
50	0.00	0.00	0.00	0.00	0.00	72.94	0.00	72.94	72.94
51	354.00	656.00	1010.00	34.17	0.00	415.93	13.67	463.77	1473.77
55	89.03	0.00	89.03	0.00	0.00	0.00	0.00	0.00	89.03
57	0.00	343.00	343.00	0.00	0.00	0.00	0.00	0.00	343.00
60	0.00	0.00	0.00	0.00	0.00	50.99	0.00	50.99	50.99
61	133.07	397.00	530.07	0.00	0.00	0.00	0.00	0.00	530.07
69	0.00	377.00	377.00	0.00	0.00	0.00	131.64	131.64	508.64
70	962.16	562.00	1524.16	0.00	0.00	0.00	0.00	0.00	1524.16
71	78.66	230.00	308.66	0.00	0.00	148.41	38.05	186.46	495.12
72	521.36	0.00	521.36	0.00	0.00	41.85	0.00	41.85	563.21
74	105.00	0.00	105.00	0.00	0.00	0.00	0.00	0.00	105.00
77	0.00	0.00	0.00	0.00	0.00	21.00	0.00	21.00	21.00
80	287.99	132.00	419.99	0.00	0.00	28.60	0.00	28.60	448.59
81	0.00	0.00	0.00	0.00	63.83	0.00	0.00	63.83	63.83
84	49.98	0.00	49.98	0.00	0.00	0.00	0.00	0.00	49.98
90	50.00	542.00	592.00	136.00	0.00	0.00	96.99	232.99	824.99
93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
94	263.98	94.00	357.98	0.00	0.00	20.00	0.00	20.00	377.98
96	4.33	0.00	4.33	0.00	351.98	0.00	2.00	353.98	358.31
99	1060.93	210.00	1270.93	0.00	0.00	0.00	4.33	4.33	1275.26
Average	196.42	144.77	341.19	4.86	30.13	26.19	14.02	75.21	416.40
Median	78.66	0	146.66	0	0	0	0	13.68	324

Table 2-4. Exterior Abatement by Method for Each House (ft^2)

House	Encapsulation/Enclosure			Removal					Total Abated
	Encapsulate	Enclosure	Total E/E	Removal	Heat Gun	Chemical Stripping	Remove/ Replace	Total Removal	
07	103.64	194.00	297.64	0.00	0.00	0.00	67.50	67.50	365.14
09	376.97	0.00	376.97	0.00	0.00	0.00	0.00	0.00	376.97
10	152.31	0.00	152.31	0.00	0.00	0.00	0.00	0.00	152.31
11	141.23	0.00	141.23	0.00	0.00	0.00	0.00	0.00	141.23
17	140.67	0.00	140.67	0.00	0.00	0.00	0.00	0.00	140.67

House	Encapsulation/Enclosure			Removal					Total Abated
	Encapsulate	Enclosure	Total E/E	Removal	Heat Gun	Chemical Stripping	Remove/ Replace	Total Removal	
07	103.64	194.00	297.64	0.00	0.00	0.00	67.50	67.50	365.14
18	107.31	0.00	107.31	0.00	0.00	0.00	0.00	0.00	107.31
21	0.00	0.00	0.00	0.00	194.58	761.00	0.00	955.58	955.58
24	167.00	100.00	267.00	0.00	0.00	0.00	204.80	204.80	471.80
25	210.30	0.00	210.30	0.00	0.00	0.00	0.00	0.00	210.30
31	980.44	0.00	980.44	0.00	0.00	0.00	61.50	61.50	1041.94
39	0.00	1682.00	1682.00	0.00	390.62	0.00	0.00	390.62	2072.62
40	1513.49	0.00	1513.49	0.00	0.00	0.00	0.00	0.00	1513.49
41	542.96	0.00	542.96	0.00	0.00	0.00	17.32	17.32	560.28
44	0.00	420.00	420.00	0.00	0.00	0.00	223.79	223.79	643.79
46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	256.00	256.00	0.00	0.00	252.50	56.25	308.75	564.75
51	1656.00	0.00	1656.00	0.00	0.00	145.67	0.00	145.67	1801.67
55	781.81	22.00	803.81	0.00	0.00	0.00	0.00	0.00	803.81
57	0.00	0.00	0.00	0.00	24.00	1176.28	0.00	1200.28	1200.28
60	0.00	1367.67	1367.67	0.00	0.00	61.65	17.67	79.32	1446.98
61	185.44	33.49	218.94	0.00	0.00	0.00	0.00	0.00	218.94
69	0.00	209.00	209.00	0.00	146.73	0.00	4.33	151.06	360.06
70	127.30	1366.17	1493.47	0.00	0.00	0.00	0.00	0.00	1493.47
71	0.00	150.00	150.00	0.00	0.00	141.80	12.75	154.55	304.55
72	836.03	0.00	836.03	0.00	0.00	0.00	0.00	0.00	836.03
74	80.56	0.00	80.56	0.00	0.00	0.00	0.00	0.00	80.56
77	187.80	922.00	1109.80	0.00	0.00	0.00	0.00	0.00	1109.80
80	181.00	0.00	181.00	0.00	0.00	0.00	21.00	21.00	202.00
81	0.00	150.00	150.00	0.00	257.79	0.00	15.75	273.54	423.54
84	1300.55	55.00	1355.55	0.00	0.00	0.00	121.50	121.50	1477.05
90	0.00	1839.00	1839.00	161.50	0.00	37.00	42.67	241.17	2080.17
93	308.81	0.00	308.81	0.00	0.00	0.00	0.00	0.00	308.81
94	368.10	229.60	597.70	0.00	0.00	19.37	67.20	86.57	684.27
96	0.00	123.00	123.00	0.00	168.34	0.00	84.00	252.34	375.34
99	759.83	60.00	819.83	5.33	0.00	0.00	101.25	106.58	926.42
Average	320.27	262.26	582.51	4.77	33.77	74.15	31.98	144.67	727.20
Median	141.23	22	297.64	0	0	0	0	61.5	560.28

XRF testing was used to prioritize houses for abatement in the HUD Demonstration. Generally, if paint lead loadings greater than 1.0 mg/cm^2 were measured in a house, then the house was abated. However, there were some houses with lead loadings above this threshold that were not abated. Table 2-5 displays the area of each unabated house with lead loadings at or above the 1.0 mg/cm^2 threshold separately for interior and exterior components. Averages and medians are listed at the bottom of the table. Note that at least 50 percent of the houses had zero square feet of the components measured with XRF level at or above 1.0 mg/cm^2 (both for interior and exterior).

Table 2-5. Square Footages of Components with XRF Results at or Above 1.0 mg/cm^2 in Unabated Houses

House	Area (ft^2) with Lead at or Above 1.0 mg/cm^2	
	Interior Components	Exterior Components
03	0	0
14	100	190
16	2.5	0
19	0	0
22	0	0
27	5	0
28	56	0
33	0	70
45	0	0
49	0	625
53	0	120
65	0	146.7
68	110	0
78	125	40
79	116	0
88	105	34.2
95	0	0
Average	36.4	72.1
Median	0	0

The interior and exterior of each housing unit was classified as either control, predominantly encapsulated/ enclosed, or predominantly removal, based on the amount of abatement performed. Some abated houses had an exterior classification different from the interior classification. Table 2-6 lists the number of housing units in each category.

Table 2-6. Distribution of Unabated, E/E, and Removal Houses; Interior and Exterior Abatement History

Location	Control	Abated		
		E/E	Removal	Unabated
Interior	17	25	9	1*
Exterior	17	28	6	1**

* House 93 had no interior abatement performed, but the exterior was abated primarily by E/E methods.

** House 46 had no exterior abatement performed, but the interior was abated primarily by removal methods.

2.5 DESCRIPTIVE PLOTS

Figures 2-6 and 2-7 present the geometric mean lead loading, lead concentration, and dust loading results by sample type for unabated houses and abated houses, respectively. These plots can be used to compare the three types of measurements across sample types and house types. With a single exception (exterior entryway dust loading in abated houses), the highest lead loadings, dust loadings, and lead concentrations were obtained from window channel samples. Also, the geometric mean lead concentrations were similar for all three soil sample types, though the lead concentrations in foundation samples from abated houses were highest.

An initial assessment of the abatement procedures can be made by examining Figures 2-8, 2-9, and 2-10. In Figure 2-8, the

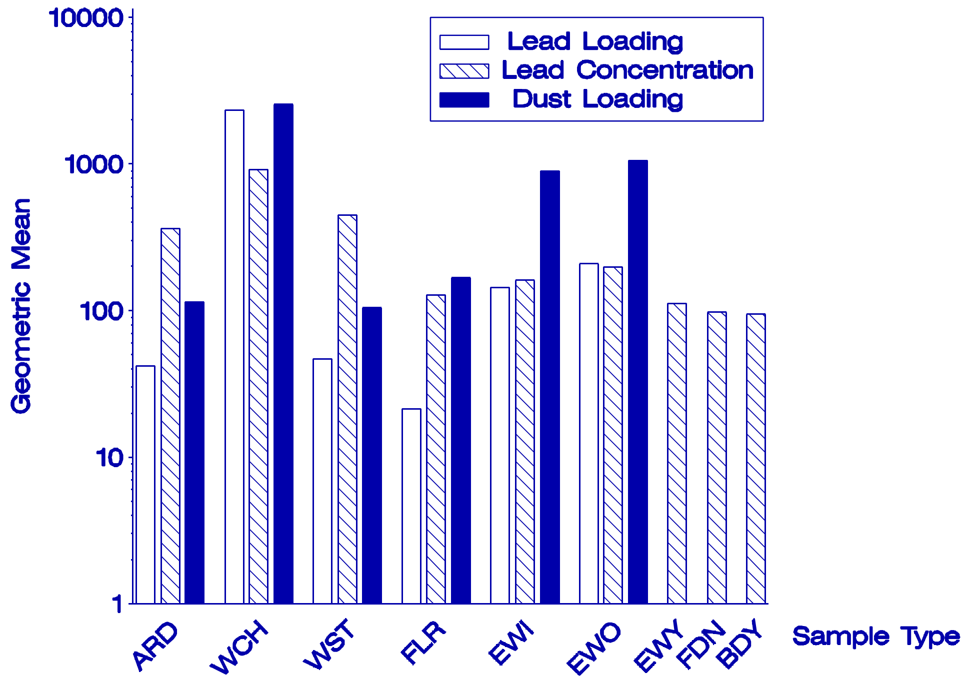


Figure 2-6. Geometric mean lead loading (µg/ft^2), lead concentration (µg/g), and dust loading (mg/ft^2) by sample type: Unabated units.

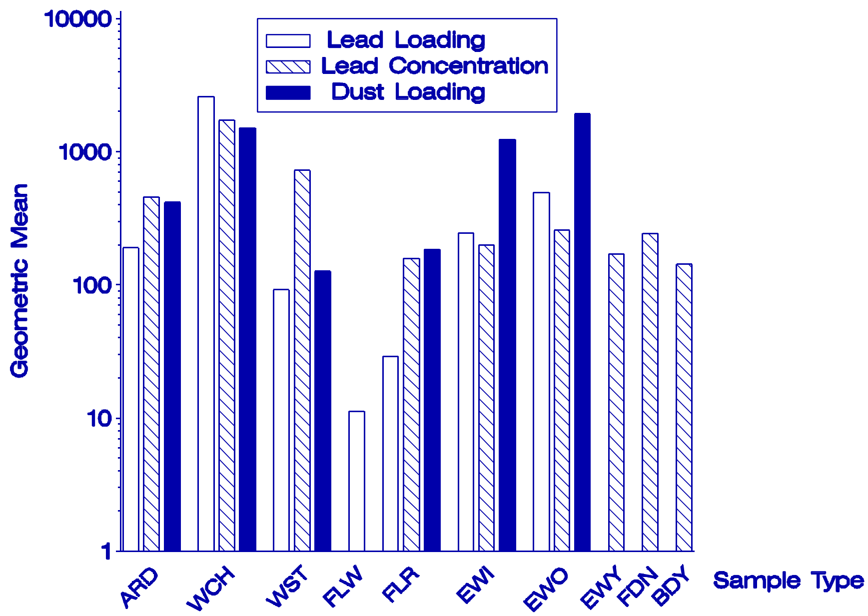


Figure 2-7. Geometric mean lead loading (µg/ft^2), lead concentration (µg/g), and dust loading (mg/ft^2) by sample type: Abated units.

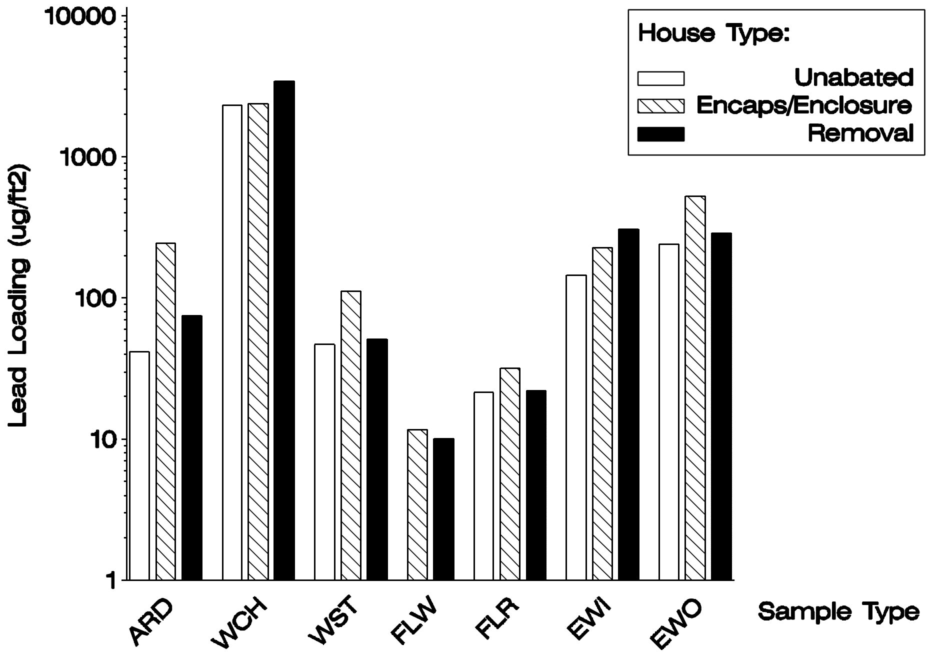


Figure 2-8. Lead loading (µg/ft^2) by sample type and method of abatement.

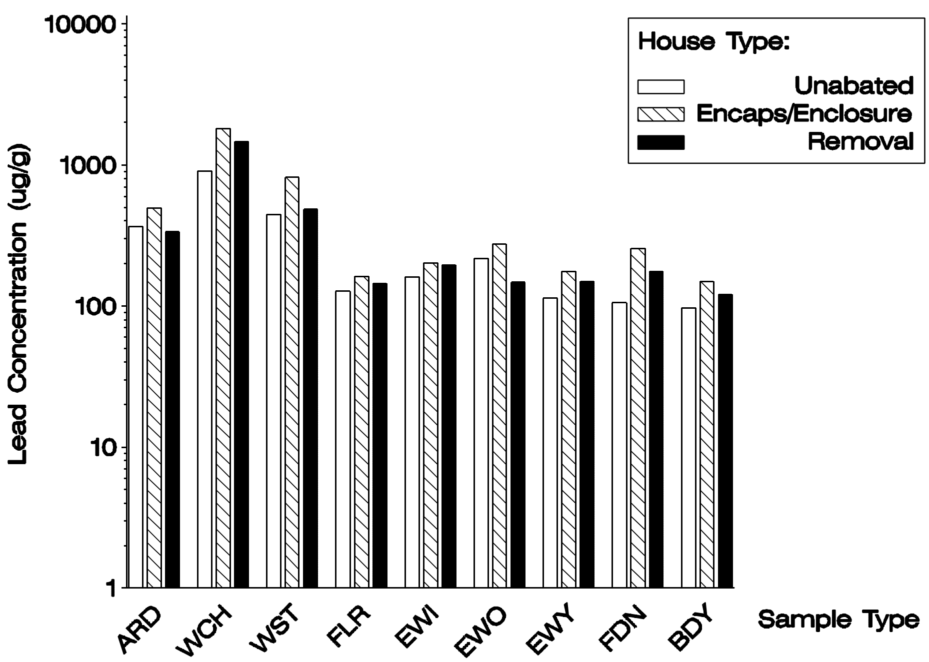


Figure 2-9. Lead concentration (µg/g) by sample type and method of abatement.

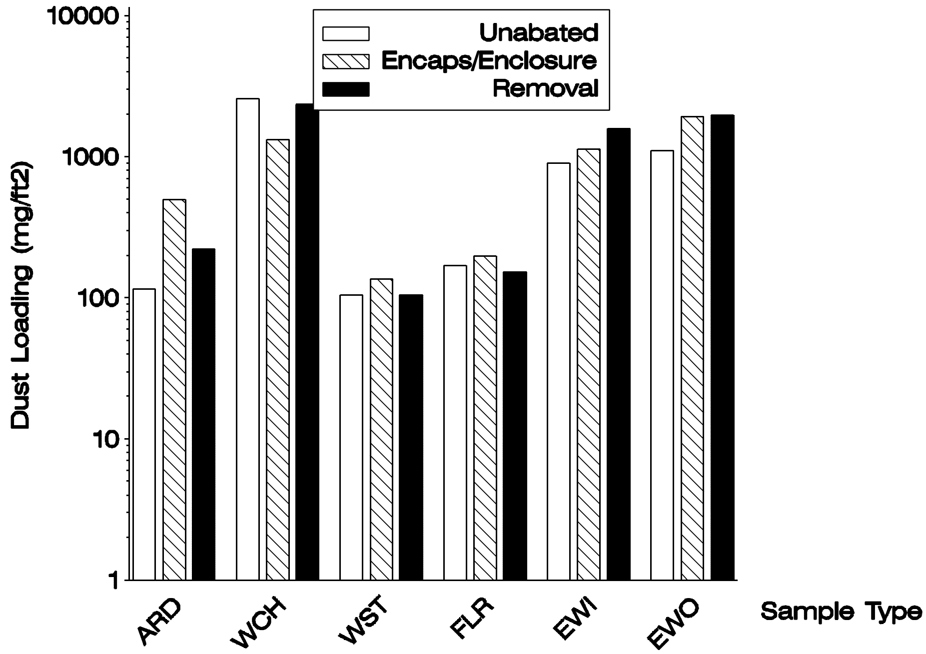


Figure 2-10. **Dust loading (mg/ft^2) by sample type and method of abatement.**

geometric mean lead loading for control, predominantly encapsulated/enclosed, and predominantly removal houses are displayed by sample type. Notice that because the floor samples collected with wipes were only taken from abated houses, there is no unabated bar. (Wipe samples are collected only for a quality control comparison with vacuum samples.) For interior sample types, abated houses were classified according the predominant method of interior abatement. For exterior sample types, abated houses were classified according to the predominant method of exterior abatement. Figures 2-9 and 2-10 present similar bar charts for lead concentration and dust loading, respectively. Section 4 discusses the model estimates of these geometric means after controlling for different levels of abatement and other factors. For all sample types, the predominantly encapsulated/enclosed houses exhibited the highest geometric mean lead concentrations. The geometric mean lead concentration for predominantly removal units were usually higher than for unabated houses, with the exception of air ducts and entryway exterior samples. This pattern was not duplicated in either the lead loading or dust loading results. The results for unabated houses, however, were usually lowest. A striking exception is evident for window channel samples. The geometric mean lead loading and dust loading for window channels were actually higher for unabated houses than for predominantly encapsulated/enclosed houses.

2.6 ESTIMATED LEVEL OF DETECTION AND LEVEL OF QUANTIFICATION

In order to assess the significance of the lead concentration and lead loading results reported, it is important to understand the sensitivity of the laboratory procedures employed. This assessment may be performed by considering two parameters of sensitivity, the estimated level of detection (ELOD) and the level of quantification (LOQ). Both parameters are stated in terms of the instrument response concentration, which is the amount of lead (μg) per dilution volume (mL) in instrument samples. The ELOD is a practical upper bound on the estimated concentration (μg/mL) that would result from the analysis of samples which contain no lead. The LOQ, in turn, is the smallest concentration which will consistently produce estimated concentrations that are within 30% of the true concentration.

Table 2-7 contains the ELODs for the 24 instrument batches of regular field samples. Three percent (35 out of 1169) of the regular samples had concentrations below the ELOD for their instrument batch. These samples are detailed in Table A-3 of the Appendix.

The LOQ was determined from information outlined in the memorandum, "Potential Instrumental Measurement Error for Lead Analysis," dated September 21, 1992. This memo, portions of which are excerpted in Table 2-8, documented the instrumental measurement error for a series of known lead concentrations ranging from 0.02 to 0.50 µg/mL. The results suggested an LOQ of 0.208 µg/mL.

Approximately 19% (226 out of 1169) of the regular field samples had concentrations below the LOQ. To examine the potential impact of these samples on the statistical analysis, two sets of statistical analyses were performed. In the first set of analyses, the concentrations below the ELOD were set equal to the ELOD. No modifications were made to concentrations above the ELOD but below the LOQ. In the second set of analyses, all concentrations below the LOQ were set equal to the LOQ. The mixed model described in Section 4 was fitted separately to each set of data. Since the second set of analyses agreed with the first, only the results of the first set of analyses were presented in this report. The only notable disagreement between the two sets of analyses was that the difference in lead concentrations in air ducts between abated and control homes was not as great by the second analysis.

Table 2-7. Estimated Level of Detection by Instrument Batch

Instrument Batch	ELOD µg/mL	Instrument Batch	ELOD µg/mL
E04272A	0.0298	E06122A	0.0370
E04292A	0.0138	E06152A	0.0254
E05042A	0.0383	E06242A	0.0263
E05072B	0.0324	E06262A	0.0655
E05122B	0.0308	E06292A	0.0527
E05132A	0.0255	E07142A	0.0300
E05192A	0.0293	E07212A	0.0593
E05262A	0.0461	E07242A	0.0354
E05272A	0.0634	E07302A	0.0514
E06022A	0.0400	E08032A	0.0272
E06042A	0.0465	E08062A	0.0349
E06112A	0.0553	E08242A	0.0240

Table 2-8. Potential Instrumental Measurement Error: Calculated Results

Lead Concentration (µg/mL)	Average Response (µg/mL)	n-1 Standard Deviation	% Relative Standard Deviation
0.02	0.03303	0.01682	50.91%
0.03	0.04253	0.01893	44.50%
0.05	0.06625	0.02012	30.36%
0.07	0.08816	0.01891	21.45%
0.10	0.11709	0.02000	17.08%
0.30	0.31963	0.02643	8.27%
0.50	0.52871	0.02155	4.08%

3.0 STATISTICAL MODELS

This section discusses the statistical models that were fitted to the lead loading, lead concentration, and dust loading data. Also discussed are centering and scaling of design variables to produce easily interpretable model parameters. The stepwise regression and mixed model procedures used to arrive at final models are defined and model parameters are related to specific hypotheses of interest.

Various factors were considered for inclusion in the model. These included abatement and non-abatement factors as fixed effects. To account for within-house and within-room correlation and to estimate house-to-house, and room-to-room variability, random house and room means were included. A discussion of typical levels for the fixed effects, as well as what level was considered as nominal is presented in Section 3.2.

3.1 MIXED RANDOM AND FIXED EFFECTS MODEL

This section describes the statistical models that were fitted to the observed lead loadings, lead concentrations, and dust loadings. These models are the basis for the statistical analyses described in Sections 4 and 5.

The following model contains all of the design factors considered in the study, random effects for house-to-house and room-to-room variation, and additional explanatory variables or covariates. This model was fitted separately to the data for air duct, interior entryway, window channel, and window stool dust samples.

$$\begin{aligned} \ln(C_{ij}) = {} & \ln('') + U_i + R_{ij} + \ln(\$_{PI})PI_i + \ln(\$_{PID})PID_i \\ & + \ln(\$_{SI})SI_i + \ln(\$_{SID})SI_i\,PID_i + \ln(\$_{POD})POD_i \\ & + \ln(\$_{SO})SO_i + \ln(\$_{SOD})SO_i\,POD_i + \ln(\$_{PR})PR_{ij} \\ & + \ln(\$_{PRD})PRD_{ij} + \ln(\$_{SR})SR_{ij} + \ln(\$_{SRD})SR_{ij}PRD_{ij} \end{aligned} \qquad [3.1]$$

$$+ \ln(\underset{\sim}{(})\underset{\sim}{X}$$

for

$i = 1, 2, \ldots , \#$ houses

$j = 1, 2$ or 3 rooms

where

C_{ij} = measured lead concentration, lead loading, or dust loading in the jth room in the ith house,

" = overall geometric average lead concentration in unabated houses for nominal values of covariates,

U_i = random effect for the ith house; assumed to follow a normal distribution with mean zero and standard deviation F_U,

R_{ij} = random effect for the jth room in the ith house; assumed to follow a normal distribution with mean zero and standard deviation F_R,

$\$_{PI}$ = fixed multiplicative effect associated with a house that has undergone abatement; $\$_{PR}$ is similarly defined for room-level abatement,

PI_i = 1 if abatement was performed in the ith house and zero otherwise; PR_{ij} is similarly defined for room-level abatement,

$\$_{PID}$ = fixed multiplicative effect of interior abatement by E/E methods rather than removal methods; $\$_{POD}$ and $\$_{PRD}$ are similarly defined for outside abatement and room-level abatement,

PID_i = the percentage of interior abatement that was performed by E/E methods; POD_i and PRD_{ij} are similarly defined for exterior abatement and room-level abatement,

$\$_{SI}$ = multiplicative effect of increasing the log-square footage of abatement; $\$_{SO}$ and $\$_{SR}$ are similarly defined for outside abatement and room-level abatement,

SI_i = log-square footage of interior abatement in the ith house or $\ln(1+SFI_i)$ where SFI_i is the square footage of interior abatement in the ith house; SO_i and SR_{ij} are similarly defined for outside abatement and room-level abatement,

$\$_{SID}$ = ratio of the multiplicative effect of increasing the log-square footage of interior abatement by E/E methods to the multiplicative effect of the same increase in the log-square footage of interior abatement by removal methods; $\$_{SOD}$ and $\$_{SRD}$ are similarly defined for outside abatement and room-level abatement.,

$\underset{\sim}{X}$ = vector of additional covariates, and

$\underset{\sim}{(}$ = vector of multiplicative effects associated with increases in the corresponding covariates in the vector X.

The additional explanatory variables (covariates, $\underset{\sim}{X}$) that were considered for inclusion in the model are listed in Appendix B. The variables considered included questionnaire responses, field inspection variables, and measurements taken during the HUD Demonstration. Explanatory variables that were found to be significant for at least one of the sample types are listed by category in the second column of Table 3-1. Nominal values of these covariates and the sample types for which the covariates are significant are listed in the third and fourth columns.

In the model, the " term represents the geometric average lead level that can be expected in houses where no abatement was performed (unabated houses) for nominal values of the covariates included in the model. The random effect term for houses (U_i) allows each housing unit to have its own average lead level. The random effect terms for rooms (R_{ij}) allow each room within the house to have its own average lead level.

The terms PI_i and PID_i and the corresponding coefficients, $\$_{PI}$ and $\$_{PID}$, allow estimation of the effect of abatement and also allow a distinction between the effects of different abatement methods. $\$_{PI}$ characterizes the abatement effect without distinguishing between E/E methods and removal methods. $\$_{PID}$ characterizes the difference in the interior abatement effects

Table 3-1. Explanatory Variables that are Significant for at Least One Sample Type

Explanatory Variable Category	Explanatory Variable	Nominal Value	Sample Types for Which Explanatory Variable is Significant
Abatement	Abatement contractor	Average across contractors	ARD
	Total Interior Abatement	282 for Typical E/E 61 for Typical Removal 180 for Typical Abated	FLR, WCH, WST
	Total Exterior Abatement	628 for Typical E/E 260 for Typical Removal 519 for Typical Abated	WCH, FDN
	Phase of HUD Demonstration (of three) in which residence was abated	Average across phases	WST
	HUD XRF or AAS measure of paint lead loading	Control: 0.10 (mg/cm^2) Abated: 0.44 (mg/cm^2)	FDN
	Specific removal method used in a room – chemical stripping – remove and replace – heat gun – removal	 15% 15% 30% 40%	WCH
Substrate	Substrate type	Average across substrates	FLR, EWI, WCH, FLW
	Substrate condition	Good	ARD, WCH
Cleanliness	Frequency of wet mopping uncarpeted floors	12/month	ARD
	Frequency of window stool dusting	1/month	ARD
	Frequency of vacuuming uncarpeted floors	12/month	EWI, EWO, FLR
Occupation	Wearing home work clothes from an occupation with potential lead contamination	No	WST, EWY
	Resident employed in welding occupation	No	FDN, FLR
	Resident employed in salvage occupation	No	BDY
	Resident employed in paint removal occupation	No	BDY
Activities	Frequency of removing paint at home	Not in last 6 months	EWI, FDN
	Frequency of pipe or electrical component soldering	Not in last 6 months	BDY
Other resident factors	Year house was built	Control: 1943 Abated: 1926	BDY, FDN, EWY
	Number of children (between ages of 7 and 17)	0	EWI
	Months at residence	18	FDN
	Ownership of home	Owner	FDN
	Number of pets	0	FLR
Sampling deviations	Air duct samples taken from cover of air duct	No	ARD
	Window channel samples taken with small nozzle	No	WCH

for E/E methods versus removal methods. Exterior and room-level abatement effects are handled similarly in the model.

The term SI_i and the corresponding coefficients, $\$_{SI}$ and $\$_{SID}$, allow the effect of the amount of interior abatement, on a per log-square foot abated basis, to be estimated by the model. $\$_{SI}$ characterizes the interior abatement effect per log-square foot abated without distinguishing between E/E methods and removal methods. $\$_{SID}$ characterizes the difference in the interior abatement effects per log-square foot abated for E/E methods versus removal methods. Exterior and room-level abatement effects are handled similarly in the model.

In the case of floor dust vacuum samples, an additional within-room random error term was added to model [3.1],

$,_{ijk}$ = random effect for the kth sample in the jth room of the ith house.

Floor dust wipe samples were taken from only one location in each of the abated houses. Therefore, no room level effects were included in the model, nor can differences between abated and unabated houses be estimated. The following model was used for these samples:

$$
\begin{aligned}
\ln(C_{ij}) = \ln(") + U_i + R_{ij} &+ \ln(\$_{PID})PID_i \\
&+ \ln(\$_{SI})SI_i + \ln(\$_{SID})SI_i\,PID_i + \ln(\$_{POD})POD_i \\
&+ \ln(\$_{SO})SO_i + \ln(\$_{SOD})SO_i\,POD_i \\
&+ \ln(\underset{\sim}{(})X.
\end{aligned}
\qquad [3.2]
$$

The model fitted to the data for exterior entryway dust samples is

$$
\begin{aligned}
\ln(C_{ij}) = \ln(") + U_i + S_{ij} &+ \ln(\$_{PI})PI_i + \ln(\$_{POD})POD_i \\
&+ \ln(\$_{SO})SO_i + \ln(\$_{SOD})SO_i\,POD_i + \ln(\underset{\sim}{(})\underset{\sim}{X}
\end{aligned}
\qquad [3.3]
$$

where

C_{ij} = measured lead concentration at ith house,

S_{ij} = random effect for the jth side of ith house; assumed to follow a normal distribution with mean zero and standard deviation F_S,

and all other terms are defined as above. For exterior samples, the random side effect, S_{ij} takes the place of the random room effect, R_{ij} .

For foundation soil, boundary soil, and entryway soil, an additional within-side of house component of variation is added to model [3.3]:

E_{ijk} = random effect for the kth sample on the jth side of ith house; assumed to follow a normal distribution with mean zero and standard deviation F_E,

The third objective of this study was to investigate the relationships between lead in household dust and lead from other sources. The estimated house-level and room/side-level random effects for the different sample types provide a basis for this investigation. A discussion of these relationships is provided in Section 5.0.

3.2 CENTERING AND SCALING OF COVARIATES

Several covariates included in the models were centered and scaled so that the model parameters would have more meaningful interpretations. In order to determine the appropriate centering and scaling parameters, three classes of abated houses were identified: (1) predominantly E/E, (2) predominantly removal, and (3) abated. The third class is the combination of the first and second classes. As illustrated above in Tables 2-3 and 2-4, a different combination of E/E and removal methods was applied in each house. Each house was classified separately for interior and exterior abatement. For interior sample types, if the percentage of interior abatement performed by E/E methods was more than 50%, then the house was classified as predominantly E/E. Otherwise, it was classified as predominantly removal. A similar approach was used for exterior sample types.

For each of the three classes of abated houses two quantities were determined:

- Typical percentage abated by E/E methods, and
- Typical square footage abated.

These values are reported in Table 3-2 for interior, exterior, and room-level abatement. The typical percentage abated by E/E methods was determined by taking an average across all houses in the class.

A correlation was observed between total square feet abated in a house and the method used to perform the abatement. Typically, significantly more square feet were abated when E/E methods were used than when removal methods were used. This occurred both indoors and outdoors. Therefore, the typical square footage abated was treated as a function and allowed to vary with the percentage abated by E/E methods. To accomplish this, a simple linear regression of log-square feet abated versus percent abated by E/E methods was fitted to the data for all abated houses. Figure 3-1 displays the regression relationship for interior abatement. Similar regression relationships were developed for exterior and room level abatement.

The typical square footage abated values reported in Table 3-2 are taken from the regression relationship for the typical percentage abated by E/E methods. Taking interior abatement for example, a predominantly E/E house with 93% E/E abatement is predicted to have 282 total square feet of interior abatement.

Similarly, a predominantly removal house with 4% E/E abatement is predicted to have only 61 total square feet of interior abatement. Finally, an abated house with 67% E/E abatement

Table 3-2. Average Percent Abated by E/E Methods, by Abatement Method Classification for Interior, Exterior and Room Level Abatement

Level	Typical % Abated by E/E Methods			Typical Square Footage Abated		
	E/E	Removal	Abated	E/E	Removal	Abated
Interior	93	4	67	282	61	180
Exterior	92	27	78	628	260	519
Room	96	3	69	70	36	58

Table 3-3. Centering and Scaling Parameters for Model Covariates

Covariates	Value Subtracted		Value Divided By
	Control	Abated	
PID	0	67%	89%
POD	0	78%	65%
PRD	0	69%	93%
SI	0	ln(57)+0.0172*(E/E%)	ln(2)
SO	0	ln(180)+0.0136*(E/E%)	ln(2)
SR	0	ln(35)+0.0072*(E/E%)	ln(2)
PR	0	1	-1

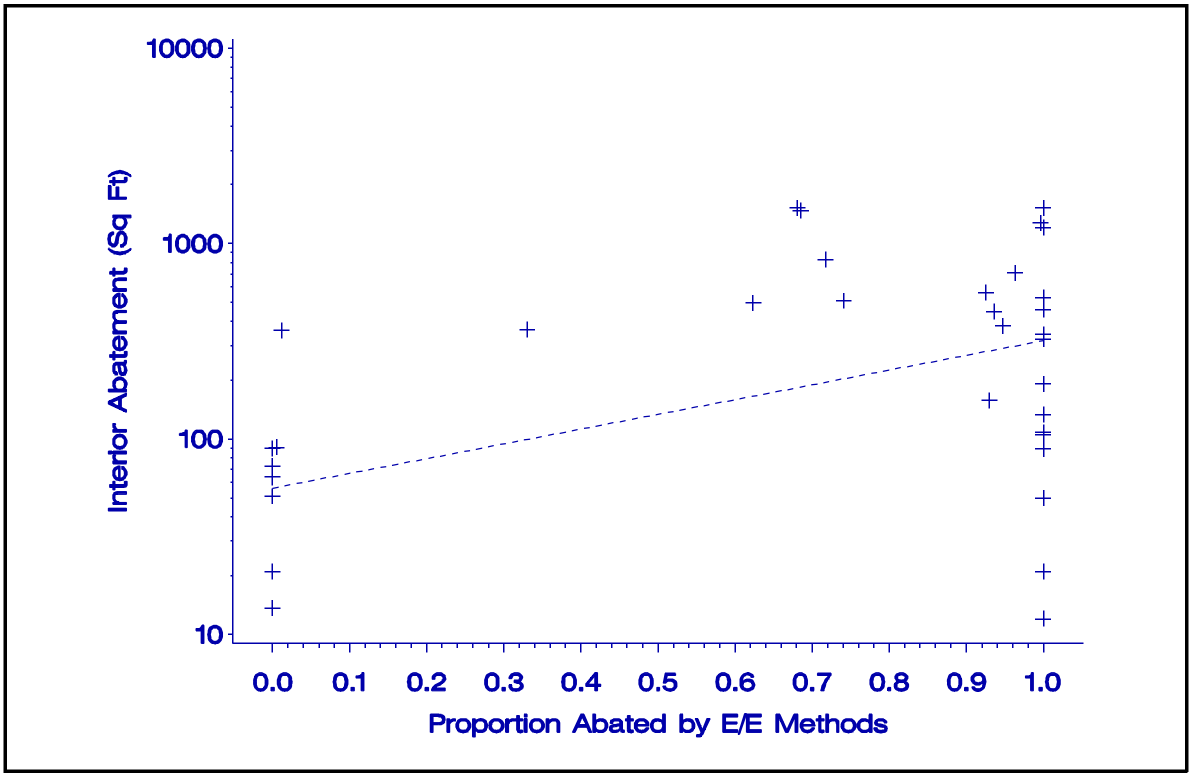


Figure 3-1.Total square feet abated indoors vs. percent encapsulated/enclosed indoors: Abated units.

is predicted to have 180 total square feet of interior abatement. The typical square footage abated values in Table 3-2 for exterior and room level abatement were determined in a similar fashion.

Table 3-3 describes how the values presented in Table 3-2 were used to center and scale the model covariates so that the model estimates have a meaningful interpretation. Table 3-4 displays the interpretation of each of these factor effects after transformation. These interpretations are consistent with the hypotheses we wish to test, as will be discussed in Section 3.4. For abated houses, PID, POD, and PRD values were centered by subtracting off the typical percent abated by E/E methods for an "abated" house. These values were then scaled by dividing the

Table 3-4. Parameter Interpretation After Centering and Scaling

Parameter	Interpretation
$\$_{PI}$	Ratio of the expected lead level in a typical abated room in a typical abated unit[a] to the expected lead level in a control unit
$\$_{PO}$	Ratio of the expected soil lead level for a typical abated unit[a] to the expected soil lead level for a control unit
$\$_{PR}$	Ratio of the expected lead level in a control room in a typical abated unit[a] to the expected lead level in a typical abated room in the same abated unit
$\$_{PID}$	Ratio of the expected lead level in a typical abated room in a typical E/E unit[a] to the expected lead level in a typical abated room in a typical removal unit
$\$_{POD}$	Ratio of expected soil lead level for typical E/E unit[a] to expected soil lead level for typical removal unit
$\$_{PRD}$	Ratio of the expected lead level in a typical E/E room in an abated unit to the expected lead level in a typical removal room in the same abated unit
$\$_{SI}$	Multiplicative effect of doubling the square footage of interior abatement in a typical abated unit[b]
$\$_{SO}$	Multiplicative effect of doubling the square footage of exterior abatement in a typical abated unit[b]
$\$_{SR}$	Multiplicative effect of doubling the square footage of room-level abatement in a typical abated room[b] while holding the house total square footage constant and mix of unit level abatement constant
$\$_{SID}$	Ratio of the multiplicative effect of doubling the square footage of interior abatement in a typical E/E unit[b] to the multiplicative effect of doubling the square footage of interior abatement in a typical removal unit[b]
$\$_{SOD}$	Ratio of the multiplicative effect of doubling the square footage of exterior abatement in a typical E/E unit[b] to the multiplicative effect of doubling the square footage of exterior abatement in a typical removal unit[b]
$\$_{SRD}$	Ratio of the multiplicative effect of doubling the square footage of room-level abatement in a typical E/E room[b] to the multiplicative effect of doubling the square footage of room-level abatement in a typical removal room[b] while holding the house total square footage constant and mix of unit level abatement constant

(a) Typical with respect to both E/E% and square footage abated as indicated in Table 3-2.

(b) Typical with respect to E/E% as indicated in Table 3-2 but with varying square footage abated.

centered variable by the difference between the typical percent abated by E/E methods for a typical "E/E" house minus a typical "removal" house. For example, to obtain the variable PID, 0.67 was subtracted from the percent of interior abatement performed by E/E methods, and then this difference was divided by 0.89 (= 0.93 - 0.04). The result is a variable whose effect can be interpreted as the following ratio:

$$\frac{\text{Expected lead level in a typical abated room in a typical E/E house}}{\text{Expected lead level in a typical abated room in a typical removal house}}.$$

SI, SO, and SR values were centered by subtracting off the logarithm of the predicted square footage abated based on the regressions versus E/E percentage discussed above. These values were then scaled by dividing by ln(2). Finally for abated houses, PR (the unabated room indicator) was subtracted from one (making abated rooms the default for abated houses). The values of these variables in unabated houses were left as zero.

Information on many of the factors determined to be significant was obtained during an interview with a resident of each house sampled. A summary of the interview results is provided in Appendix E. Before models were fitted, these factors were also centered at nominal levels. Centering was accomplished by subtracting off the nominal value reported in Table 3-1. Some factors, such as age of home and XRF measures were very correlated with the abatement indicator. In these cases a nominal level was determined both for the unabated houses and for the abated houses. The estimated effect then represents the effect of the factor above and beyond the effect of abatement. These nominal levels are reported again in Section 4 in each table where estimates are given, along with the scaling factor used. The selection of nominal values is also discussed in more detail in Section 4.

The purpose of including XRF measures as a covariate was to control for differences in pre-abatement lead levels. In rooms where XRF measures were taken during the HUD Demonstration, a geometric average was calculated. However, due to the variability in observed XRF levels, negative values were obtained in several cases. Since it is impossible to have a negative amount of lead and the smallest positive reading by the XRF was 0.1, these values were regarded as censored at 0.1 mg/cm^2, and a censored mean for the room was estimated. If only one component was measured within a room, and the reading was at or below 0 mg/cm^2, 0.05 mg/cm^2 was used in the analysis; if more than one component was measured and all were reported at or below 0 mg/cm^2, 0.07 mg/cm^2 was used.

3.3 MODEL SELECTION

The procedure used to select models to fit to the data was developed in concert with the study objectives. Specific terms corresponding to the primary design factors were included in the model to test hypotheses associated with the objectives of the study. These hypotheses are listed in Section 3.4.

Every model used in this study included the following primary design factors:

- A term to distinguish between unabated houses and abated houses (PI), and
- A term to distinguish between abatement methods (PID for interior samples, POD for exterior samples).

Models for interior dust measurements also contained:

- A term to distinguish between unabated rooms and abated rooms in abated houses (PR).

There is one exception. All wipe floor samples were taken in only one room of abated houses. Although for 4 of the 34 houses these samples were collected from a unabated room, room-level abatement effects were not estimated from the data collected by wipe sampling.

In addition to the three primary design factors, many additional factors (questionnaire data, field observations) were included to estimate other effects which may affect lead levels. The additional factors included in each model were selected using a phased stepwise regression approach.

3.3.1 <u>Phase 1: Abatement Effects (Stepwise Regression)</u>

First, stepwise regression was used to select additional abatement design factors which were significant above and beyond the effects of the three primary design factors described above. The additional abatement factors considered included square-footage abated by room, as well as a breakdown of square-footage by abatement method.

In the stepwise regression, factors were retained only if they were significant at the 5 percent level. Any factor found to be significantly associated with either lead concentration or lead loading was automatically forced to be retained in the model for the next selection phase.

3.3.2 **Phase 2: Non-Abatement Factors (Stepwise Regression)**

In a second phase of factor selection, all remaining factors were considered as candidate factors in addition to the design factors discussed above. These included questionnaire and visual observation data, HUD Demonstration Data, and other practical measures. Appendix B presents a list of all the factors considered for inclusion in the models. Stepwise regression was used again to select significant factors. Any factors found to be significant at the 5 percent level were retained for the next selection phase.

To avoid confounding, a preliminary correlation analysis was performed to screen any factors which were strongly correlated with others. For example, for 15 of the 16 homes in which a resident wore work clothes home from their occupation, their clothes were also washed at home. Therefore, only the former was included as a candidate factor in the stepwise regression. Specifically, if any factor was more than 80 percent correlated with another, one of the factors was excluded from the models. The factor with the most complete data was used in fitting the models.

3.3.3 **Phase 3: Mixed Model Screening (Backward Elimination)**

Phase 1 and Phase 2 identified a subset of factors with some association with lead levels. However, due to software limitations, the stepwise regressions were based on fixed effect models whereas it is proper to use a mixed model with random effects in the factor selection process described above. Therefore a mixed model was fitted with random house and random room/side of house effects where appropriate. Any factors not found to be significant by the mixed model analysis at the 10% level were removed from the model (aside from the three design factors described at the beginning of Section 3.3). This process was repeated, refitting the model each time and removing one factor at a time, until all factors remaining were observed as significant covariates for either lead loading or lead concentration.

The final models varied by sample type. Appendix C displays the selected factors and their estimated effects by sample type and response (lead concentration, dust loading, lead loading). This table is explained in more detail in Section 4.

3.4 <u>HYPOTHESIS TESTS</u>

Data were collected to test the following hypotheses:

H_{01}: Average lead levels in a typical abated room in a typical abated house are equivalent to average lead levels in an unabated house.

H_{02}: Average lead levels in a typical abated room in a typical E/E house are equivalent to average lead levels in a typical abated room in a typical removal house.

H_{03}: Average lead levels in a typical abated room in a typical abated house are equivalent to average lead levels in a unabated room in a typical abated house.

H_{04}: House to house differences above and beyond those explained by the models are uncorrelated.

Hypothesis H_{01} is equivalent to the hypothesis that $\$_{PI}=0$, hypothesis H_{02} is equivalent to the hypothesis that $\$_{PID}=0$, and hypothesis H_{03} is equivalent to the hypothesis that $\$_{PR}=0$. Thus, the model parameters align perfectly with the hypotheses to be tested. Hypothesis H_{04} will be tested via extensive correlation analyses in Section 5.

4.0 MODELING RESULTS

This section discusses the results of estimating the fixed effects described in Section 3. These results are based entirely on the sampling results obtained in the CAP Study. The assessment of abatement efficacy presented here is based on a comparison of levels in abated houses with levels in unabated houses previously identified as being relatively free of lead-based paint, and not on a comparison of post- to pre-abatement lead levels. Therefore, this is an indirect assessment. Comparisons of pre-abatement lead levels with the results observed in the CAP Study are discussed in Section 7, along with other study results.

Included in this section are estimates of the differences in lead loadings, lead concentrations, and dust loadings among houses with different abatement histories — primarily abated vs. unabated and encapsulated/enclosed vs. removal. This is followed by a discussion of the observed variability between houses, rooms, and sampling locations.

Effects of other specific abatement factors are also presented here, including total abatement square footage, (interior and exterior), specific removal method applied (chemical stripping, heat gun, etc.), and differences among houses abated by different contractors. In addition, systematic effects of non-abatement factors are estimated. These include ownership factors such as age of the house, and questionnaire information, such as

- occupations of residents
- ages of occupants
- measures of cleanliness
- activities of occupants
- ownership.

Some factors were associated with differences at the sample level. These include:

- Substrate type and condition
- XRF measures taken prior to abatement
- Sampling deviations.

These factors were controlled for in the analysis and their impacts were estimated. Some variables, such as XRF measures taken prior to abatement, were strongly correlated with the primary design abatement variables. As discussed in Section 3, these were adjusted so that they would not mask the effects of abatement.

4.1 SUMMARY OF MODELING RESULTS

A summary of the primary results discussed here is presented in Tables 4-1 and 4-2. Table 4-1 presents geometric mean lead loading, lead concentrations, and dust loading for each type of sample collected, along with estimates of the differences between abated houses and unabated houses, and estimates of the differences between E/E houses and removal houses. Table 4-2 provides estimates of the differences in these responses between unabated rooms of abated houses, and abated rooms of the same houses. The information in these tables is supported with further detail in Section 4.2.1.

The indirect assessment of abatement efficacy found that abatement appears to have been effective, in the sense that there is no evidence that post-abatement lead levels at abated houses are significantly different than lead levels at unabated houses found to be relatively free of lead-based paint. There were two exceptions to this statement; however, both of these exceptions were anticipated and are logically explained. First, lead concentrations in air ducts were significantly higher in abated houses than in unabated houses; air ducts were not abated in the HUD Demonstration. In addition, lead concentrations in the soil outside abated houses were significantly higher at the foundation and at the boundary than corresponding lead concentrations outside unabated houses.

Table 4-1. Summary of Effects of Significant Primary Abatement Factors

Component	Obs.	Geometric Mean in Unabated Houses Based on Model Estimates			Ratio of Levels in Abated Houses[1] to Those in Unabated Houses			Ratio of Levels in E/E Houses to Those in Removal Houses		
		Lead Load µg/ft²	Lead Conc. µg/g	Dust Load mg/ft²	Lead Load µg/ft²	Lead Conc. µg/g	Dust Load mg/ft²	Lead Load µg/ft²	Lead Conc. µg/g	Dust Load mg/ft²
Dust										
Air Duct	86	76	332	202	4.70*	1.59*	3.11	3.99*	2.01*	1.80
Window Channel	83	1604	851	1857	0.86	0.98	0.88	0.54	1.46	0.37
Window Stool	113	38	416	92	1.84	1.70	1.09	2.51	1.77	1.42
Floor (Wipe)[2]	65							0.93		
Floor (Vacuum)	233	16	137	118	1.76	1.03	1.65	2.02	1.30	1.55
Interior Entryway	90	191	183	1055	1.05	0.85	1.19	1.15	0.95	1.24
Exterior Entryway	97	220	184	1152	2.24	1.19	1.95*	1.09	1.01	1.07
Soil										
Entryway (Soil)	109		126			1.48			1.26	
Foundation (Soil)	88		86			1.82*			0.81	
Boundary (Soil)	120		86			1.63*			1.27	

[1]For interior samples, these represent ratios of levels in abated rooms of abated houses to those in unabated houses.
[2]Floor wipe samples were only collected in abated units; the geometric mean in abated units was 11.3 after controlling for significant factors.
*Significant at 5% level.

Table 4-2. Ratio of Levels of Unabated rooms to those in Abated Rooms, both Within Abated Houses

Component	Lead Loading	Lead Concentration	Dust Loading
Air Duct	0.73	0.79	0.91
Window Channel	0.39	0.61	0.65
Window Stool	0.67	0.69	0.96
Floor (Vacuum)	0.56	0.87	0.65
Interior Entryway	1.63	1.28	1.31

However, soil was also not abated during the HUD Demonstration; and these higher lead levels might in part be due to differences in the age of these houses, since on average the abated houses in this study were 17 years older than unabated houses. As with the caveat stated above, these results must also be tempered by the fact that not finding a significant difference in lead levels at abated and unabated houses for all other building components and sampling locations does not prove that no such differences exist. The CAP Study was designed to detect two-fold differences between lead levels at abated and unabated houses under specified variance assumptions. For example, although the estimate of 1.76 for the ratio of lead loadings on floors in abated to unabated houses was not significantly different from one, the 95 percent confidence interval for this ratio was from about 0.87 to 3.5. That is, differences as large as a factor of 3 could not be judged to be statistically significant.

The CAP Study also assessed abatement by comparing encapsulation and enclosure methods versus removal methods. No significant differences among lead levels could be attributed to these two types of abatement methods, except for air ducts which, as stated above, were not abated. Air duct dust lead levels were higher in houses abated primarily by encapsulation and enclosure methods than in houses abated primarily by removal methods.

With regard to the second study objective, lead levels were found to vary greatly for different media and sampling locations. Minimum individual lead concentrations for most sample types were typically on the order of 10 µg/g except in air ducts and window channels where levels were at least 50 µg/g. Maximum individual lead concentrations were lowest for boundary and entryway soil samples (1073 and 1068 µg/g, respectively) and highest for window stool and window channel dust samples (48,272 and 45,229 µg/g, respectively). Minimum individual lead loadings for all sample types were typically only 1 to 4 µg/ft^2. Maximum individual lead loadings were lowest for floor dust samples (334 µg/ft^2 by wipe and 11,641 µg/ft^2 by vacuum) and highest for window channel dust samples (244,581 µg/ft^2).

Dust lead loadings were also evaluated in comparison with the HUD interim dust standards. Geometric mean lead loadings for both floors and window stools at both abated and unabated houses were found to be well below their respective HUD standards of 200 and 500 µg/ft^2. Geometric mean floor lead loadings were also below the EPA standard of 100 µg/ft^2 (EPA, 1994). In addition, for both floors and window stools, more than 75 percent of the samples collected in the CAP Study had lead loadings below their respective standards, in both abated and unabated houses. However, geometric mean window channel lead loadings at both abated and unabated houses were found to be well above the HUD interim standard of 800 µg/ft^2, and well over half of individual observations were above this standard, at both abated and unabated houses. These results indicate that perhaps even houses identified by XRF as lacking significant amounts of lead-based paint may have levels in the window channels in excess of the HUD standard.

One cautionary note should be mentioned concerning the interpretation of the differences observed in houses abated by the different methods. Most of the houses which had extensive abatement performed were abated by E/E methods. This may suggest that lead levels were often greater in the houses selected for abatement by E/E methods. In other words, the results presented here indicating that lead levels were higher after abatement by E/E methods may simply be a reflection of higher initial paint, soil, and dust lead levels in these houses. In most cases results were not significantly different.

4.2 DETAILED MODELING RESULTS

4.2.1 Analysis of Abatement and Random Effects

This section presents estimated effects of the various abatement factors considered in the study on lead loading, lead concentration, and dust loading for each sample type collected. These estimates are to be interpreted as having been corrected for other practical effects found to be significant (e.g., ownership, XRF measurements, cleanliness, substrate, etc.). Also described in this section is uncontrolled and unexplained random variation from house to house, room to room (or side to side), and within room/side for each sample type.

In many cases these numbers are lower than the total number of samples because of missing values of significant covariates. For instance, in some cases, the housing unit resident interviewed did not know the answers to some of the questionnaire items (e.g., ownership. cleanliness measures, etc.). Table 4-3 describes the number of samples used in the statistical analysis for each sample type, the number of samples used in fitting the model, and the percentage of samples excluded from the model fits. The number of missing values were fewer than 20 for most sample types. However, for foundation soil samples, 30 observations were excluded. For this sample type, the HUD Demonstration XRF measures were found to be a significant factor and there were several observations in the CAP Study for which there was no corresponding XRF measure available. There was also a substantial proportion of samples excluded from the model fit for air ducts.

Table 4-3. Summary of Samples Excluded from Model Fit Due to Missing Data on Covariates

		Number of Samples Analyzed*	Number of Samples Included in Model Fit	Percent Excluded
Dust	Air Duct	109	86	21
	Window Channel	98	83	15
	Window Stool	113	113	0
	Floor (Wipe)	67	65	3
	Floor (Vacuum)	238	233	2
	Entryway Interior	100	90	10
	Entryway Exterior	97	97	0
Soil	Entryway	109	109	0
	Foundation	118	88	25
	Boundary	120	120	0

*Excludes samples identified as outliers. See Section 8 for a discussion of the outlier analysis.

Effects of Primary Abatement Factors

Table 4-4 displays estimates of the effects of the primary abatement factors on lead loadings. Table 4-5 displays the estimated effects of the primary abatement factors for lead concentrations. Table 4-6 provides the corresponding results for dust loadings.

The first column provides the number of samples included in the model for each sample type. The second column in these tables contains the estimated geometric mean in houses which were not abated. The estimate is to be interpreted as the average lead loading in unabated houses when the covariates included in the model are fixed at the nominal levels of other significant factors. Effects of these factors are discussed in a later section. The log standard error of these estimates appears in parentheses below each estimate.

Figure 4-1 displays estimated geometric means in unabated houses by sample type for lead loading, lead concentration and

Table 4-4. Estimates[1] of Effects of Primary Abatement Factors on Lead Loading; Controlling for Significant Covariates

(1) Sample Type	(2) No. of Samples/ Denominator Degrees of Freedom	(3) Geometric Mean in Unabated Units After Controlling for Effects of Significant Factors	(4) Ratio of Levels in Abated Rooms of Abated Units to those in Unabated Units	(5) Ratio of Levels in E/E Units to those in Removal Units	(6) Ratio of Levels in Unabated Rooms of Abated Units to those in Abated Rooms of Abated Units	Standard Deviation Estimates (7) Unit-to-Unit Log Standard Deviation	 (8) Room-to-Room Log Standard Deviation	 (9) Residual Log Standard Deviation
Air Duct (Vacuum)	86 (35)	76 (0.52)	4.70* (0.61) .016	3.99* (0.68) .049	0.73 (0.39) .432	1.52 (0.86) .002	1.18	
Window Channel (Vacuum)	83 (26)	1604 (0.60)	0.86 (0.68) .831	0.54 (0.80) .448	0.39 (0.53) .091	1.08 (0.81) .071	1.51	
Window Stool (Vacuum)	113 (60)	38.1 (0.39)	1.84 (0.50) .231	2.51 (0.57) .111	0.67 (0.43) .366	0.93 (0.75) .130	1.79	
Floor (Wipe)[2]	65 (32)			0.93 (0.34) 0.833		0.71 (0.44) .008		0.56
Floor (Vacuum)	233 (105)	16.2 (0.29)	1.76 (0.35) .105	2.02 (0.36) .053	0.56 (0.33) .087	0.00	1.27 (0.53) .000	0.93
Entryway (Interior Vacuum)	90 (34)	191 (0.31)	1.05 (0.38) .902	1.15 (0.44) .754	1.63 (0.41) .244	0.00	1.48	
Entryway (Exterior Vacuum)	97 (46)	220 (0.37)	2.24 (0.44) .071	1.09 (0.50) .869		0.91 (0.69) .076	1.47	

[1] Top value is multiplicative estimate, middle value is logarithmic standard error of estimate, and bottom value is observed significance level.
[2] Floor wipe samples were only collected in abated units; the geometric mean in abated units was 11.3 after controlling for significant factors.

* Significant at 5% level.

Table 4-5. Estimates[1] of Effects of Primary Abatement Factors on Lead Concentration; Controlling for Significant Covariates

(1)	(2)	(3)	(4)	(5)	(6)	Standard Deviation Estimates		
						(7)	(8)	(9)
Sample Type	No. of Samples/ Denominator Degrees of Freedom	Geometric Mean in Unabated Units After Controlling for Effects of Significant Factors	Ratio of Levels in Abated Rooms of Abated Units to those in Unabated Units	Ratio of Levels in E/E Units to those in Removal Units	Ratio of Levels in Unabated Rooms of Abated Units to those in Abated Rooms of Abated Units	Unit-to-Unit Log Standard Deviation	Room-to-Room Log Standard Deviation	Residual Log Standard Deviation
Air Duct (Vacuum)	86 (35)	332 (0.19)	1.59* (0.23) .049	2.01* (0.24) .006	0.79 (0.23) .301	0.00	0.79	
Window Channel (Vacuum)	83 (26)	851 (0.44)	0.98 (0.51) .970	1.46 (0.59) .529	0.61 (0.40) .217	0.80 (0.60) .074	1.12	
Window Stool (Vacuum)	113 (60)	416 (0.30)	1.70 (0.39) .176	1.77 (0.44) .199	0.69 (0.31) .251	0.80 (0.57) .054	1.30	
Floor (Vacuum)	233 (105)	137 (0.18)	1.03 (0.22) .888	1.30 (0.23) .258	0.87 (0.22) .534	0.00	0.71 (0.35) .000	0.77
Entryway (Interior Vacuum)	90 (34)	183 (0.22)	0.85 (0.27) .561	0.95 (0.31) .876	1.28 (0.26) .341	0.49 (0.41) .154	0.84	
Entryway (Exterior Vacuum)	97 (46)	184 (0.22)	1.19 (0.26) .509	1.01 (0.29) .976		0.52 (0.41) .097	0.89	
Entryway (Soil)	109 (12)	126 (0.18)	1.48 (0.21) .087	1.26 (0.24) .365		0.37 (0.35) .284	0.71 (0.38) .001	0.40

(1)	(2)	(3)	(4)	(5)	(6)	Standard Deviation Estimates		
Foundation (Soil)	88 (14)	86 (.14)	1.82* (0.20) .009	0.81 (0.28) .452		0.12 (0.23) .772	.44 (0.26) .004	0.28
Boundary (Soil)	120 (20)	86 (0.13)	1.63* (0.15) .004	1.27 (0.18) .205		0.37 (0.24) .021	0.44 (0.22) .000	0.21

[1] Top value is multiplicative estimate, middle value is logarithmic standard error of estimate, and bottom value is observed significance level.
* Significant at 5% level.

Table 4-6. Estimates[1] of Effects of Primary Abatement Factors on Dust Loading; Controlling for Significant Covariates

(1)	(2)	(3)	(4)	(5)	(6)	Standard Deviation Estimates		
						(7)	(8)	(9)
Sample Type	No. of Samples/ Denominator Degrees of Freedom	Geometric Mean in Unabated Units After Controlling for Effects of Significant Factors	Ratio of Levels in Abated Rooms of Abated Units to those in Unabated Units	Ratio of Levels in E/E Units to those in Removal Units	Ratio of Levels in Unabated Rooms of Abated Units to those in Abated Rooms of Abated Units	Unit-to-Unit Log Standard Deviation	Room-to-Room Log Standard Deviation	Residual Log Standard Deviation
Air Duct (Vacuum)	86 (35)	202 (.48)	3.11 (.57) .053	1.80 (0.63) .356	0.91 (0.34) .777	1.45 (0.79) .001	1.00	
Window Channel (Vacuum)	83 (26)	1857 (0.46)	0.88 (0.52) .814	0.37 (0.61) .116	0.65 (0.38) .261	0.94 (0.70) .075	1.06	
Window Stool (Vacuum)	113 (60)	92 (0.21)	1.09 (0.28) .759	1.42 (0.30) .265	0.96 (0.26) .876	0.38 (0.42) .398	1.08	
Floor (Vacuum)	233 (105)	118 (0.24)	1.65 (0.29) .089	1.55 (0.31) .165	0.65 (0.25) .088	0.44 (0.43) .301	0.84 (0.45) .000	0.85
Entryway (Interior Vacuum)	90 (34)	1054 (0.22)	1.19 (0.28) .539	1.24 (0.31) .492	1.31 (0.29) .364	0.00	1.06	
Entryway (Exterior Vacuum)	97 (46)	1152 (0.25)	1.95* (0.30) .029	1.07 (0.33) .836		0.40 (0.50) .524	1.19	

[1] Top value is multiplicative estimate, middle value is logarithmic standard error of estimate, and bottom value is observed significance level.
* Significant at 5% level.

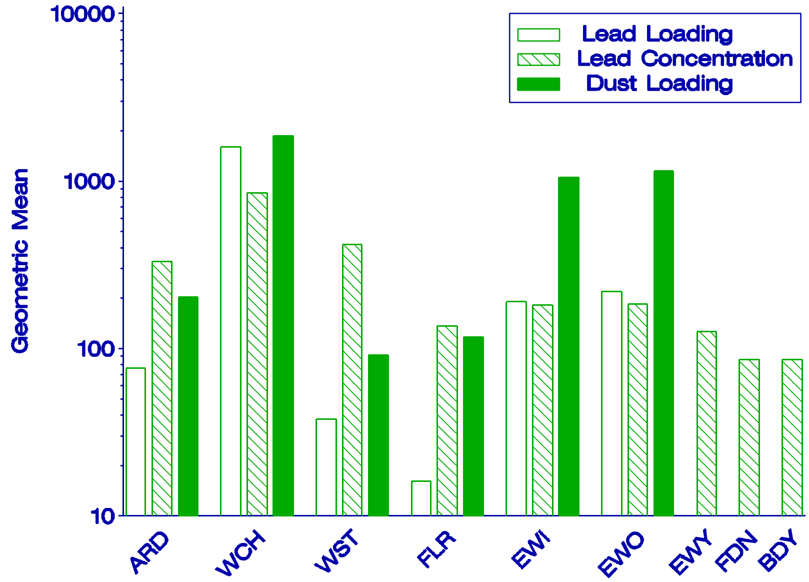


Figure 4-1. Geometric mean lead loading, (µg/ft²), lead concentration (µg/g), and dust loading (mg/ft²) in unabated units after controlling for effects of significant factors.

dust loading. Some interesting points to note regarding these geometric means are as follows:

- The highest lead loadings were observed in the window channels, and the lowest were observed on floors.
- There was very little distinction between interior and exterior entryway dust samples in unabated houses, both for lead concentration and dust loading.
- Entryway dust loadings were higher than those in the air ducts.
- Entryway soil lead concentrations were higher than boundary or foundation concentrations in unabated houses.

One thing to keep in mind when observing dust levels on floors (and interior entryways) is that substrate was an important differentiating factor. The geometric means presented are based on the observed aggregate average across substrates. The ratios of average levels on different substrates to this geometric mean are described in Section 4.2.4. For instance, dust loading and therefore, lead loading, were much higher than average on carpet.

The fourth column in Tables 4-4, 4-5, and 4-6 displays the estimated ratio of levels in abated rooms of abated houses to levels in unabated houses. The fifth column contains the estimated impact of abatement method, which should be interpreted as the ratio of levels in abated rooms of typical E/E houses to levels in abated rooms of typical removal houses (see Section 3.2). The sixth column in these tables gives an estimate of the ratio of levels in unabated rooms of abated houses to levels in abated rooms of abated houses. The log standard error and significance level of these estimates appear beneath each estimate. The latter represents the observed significance of a test that the ratio equals 1.

The following are the statistically significant results for the estimated effects of primary abatement factors:

- Air Ducts -- Lead loadings and lead concentrations were higher in abated houses than in unabated houses. Lead loadings and lead concentrations were higher in E/E houses than removal houses.

- Soil Samples -- Lead concentrations in soil outside abated houses were consistently greater than those outside unabated houses. This was especially evident in foundation samples, followed in magnitude by boundary samples.

- Exterior entryway -- Dust loadings were higher in abated houses than in unabated houses.

There were other differences observed which were not statistically significant, but worth noting:

- Floors (Vacuum) -- Lead loadings were higher in E/E houses than in removal houses (p=.053). Lead loadings and dust loadings were higher in abated houses than in unabated houses (for lead loadings p=.105; for dust loadings p=.089). Lead loadings were lower in unabated rooms of abated houses than in abated rooms (p=.087).

- Exterior Entryway -- Lead loadings were higher in abated houses than in unabated houses (p=.071).

- Soil Samples -- Lead concentrations in entryway soil samples outside abated houses were greater than those outside unabated houses (p=.087).

The estimates from columns 4, 5, and 6 of Tables 4-4, 4-5, and 4-6 are displayed graphically in Figures 4-2, 4-3, and 4-4 for lead loading, lead concentration, and dust loading, respectively. (Figures 4-2 and 4-3 duplicate Figures 1-1 and 1-2, respectively.) Reference lines are provided on these plots at a level of one. An asterisk indicates that the effect was significant at the 5 percent level. A bar which rises above the reference line for the `Abatement' factor indicates that for this sample type levels were higher in abated houses than in unabated houses. A bar which rises above the reference line for the 'Method (E/R)' factor indicates that the levels in E/E houses were higher than those in removal houses. If the 'Unabated room' effect is greater than one, then levels in unabated rooms of abated houses were higher than in abated rooms.

The most significant difference between abated and unabated houses was observed in the air ducts for lead loadings and lead concentrations. Perhaps more striking in these figures is the frequency with which the 'Method (E/R)' bar rises above the reference line. As mentioned above, this indication that E/E houses have higher lead levels than removal houses could simply be a reflection of a more serious initial lead problem in the E/E houses.

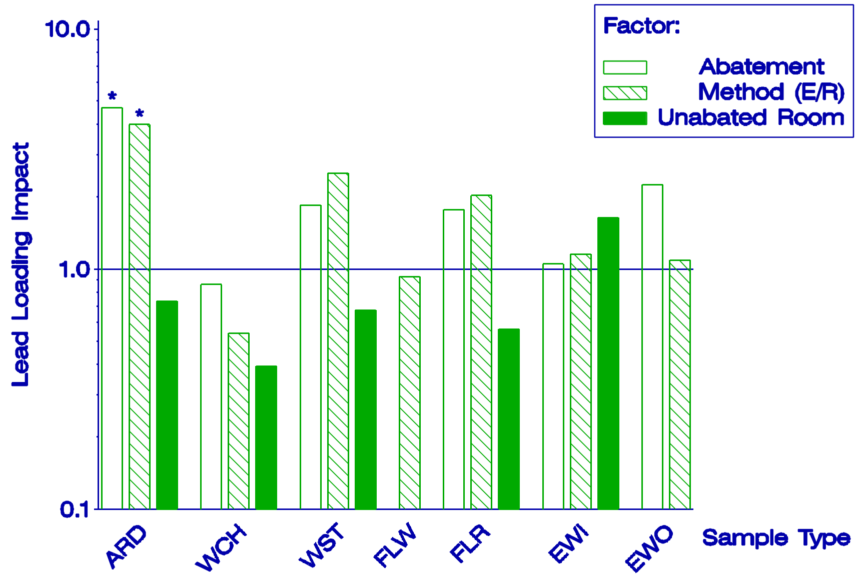
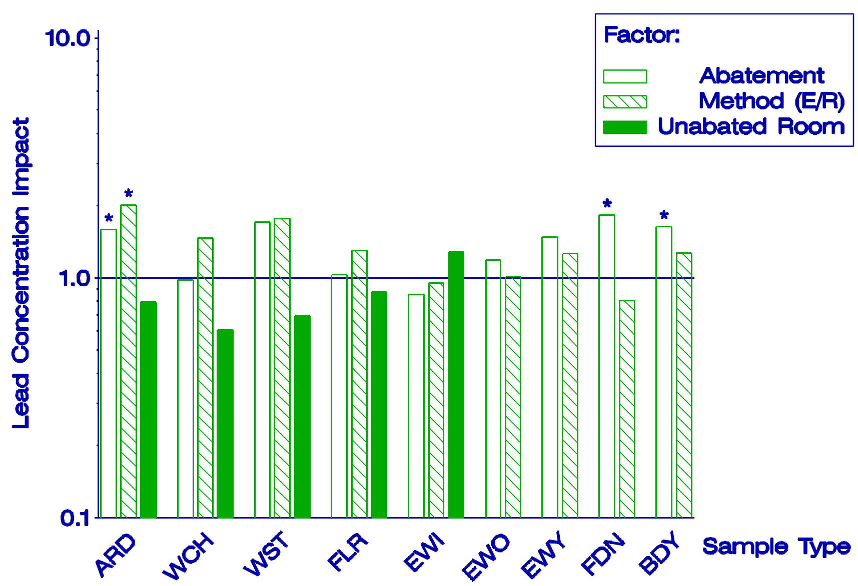


Figure 4.2 Estimated multiplicative effects of abatement from mixed model ANOVA: Lead Loading (*indicates



significance at the 5% level).

Figure 4.3 Estimated multiplicative effects of abatement from mixed model ANOVA: Lead Concentration (*indicates significance at the 5% level).

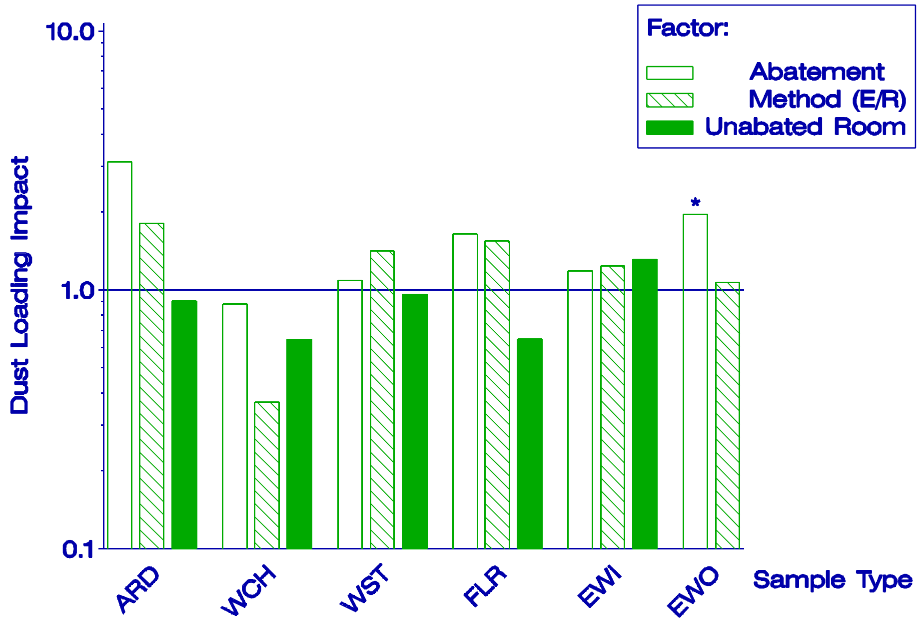


Figure 4.4 Estimated multiplicative effects of abatement from mixed model ANOVA: Dust Loading (*indicates significance at the 5% level).

Similarly, the figures portray lower levels in the unabated rooms of abated houses than in abated rooms of the same houses. This indicates that abatement performed in the rooms that needed it did not reduce lead levels to the baseline levels found in unabated rooms that did not require abatement.

In order to obtain estimates of average lead loadings, lead concentrations, or dust loadings in typical abated houses, multiply the geometric mean in column three by the ratio estimate in column four in Tables 4-4, 4-5, or 4-6, respectively. As an example, consider the estimation of the average lead concentration on floors. First, the average lead concentration on the floors of typical abated houses is obtained by multiplying the estimate of the geometric mean in unabated houses (column three of Table 4-5) by the ratio of levels in abated houses to those in unabated houses (column four of Table 4-5):

$$137 \times 1.03 = 141.1\ \mu g/g. \qquad (4\text{-}1)$$

Table 4-7. Exponents for Deriving Geometric Means in E/E and Removal Houses

Sample Type	Exponent for E/E Houses	Exponent for Removal Houses
Interior Samples	0.292	-0.708
Exterior Samples	0.215	-0.785

In order to obtain the corresponding estimates for typical E/E or typical removal houses, multiply the geometric mean for a typical abated house by the ratio estimate in column five of Table 4-4, 4-5, or 4-6, raised to the appropriate exponent in Table 4-7. For example, to obtain the estimate of average lead concentration on floors of E/E houses, multiply (4-1) by the estimate of the ratio of levels in E/E houses to those in removal houses (fifth column of Table 4-5) raised to the exponent for E/E houses in Table 4-7:

$$141.1\ (\mu g/g) \times 1.30^{0.292} = 152.3\ (\mu g/g).$$

To obtain the estimate for removal houses, multiply (4-1) by the estimate of the ratio of levels in E/E houses to those in removal houses (fifth column of Table 4-5) raised to the exponent for removal houses in Table 4-7:

$$141.1\ (\mu g/g) \times 1.30^{-0.708} = 117.2\ (\mu g/g).$$

Analysis of Random Effects

The last three columns of Tables 4-4 through 4-6 provide estimates of the house-level, room/side-level (side refers to side of house in the case of soil samples), and residual error-level variance components, after correcting for modeled factors. Only in the case of vacuum floor samples and soil samples were the room/side-level variance components estimable. The values presented are given as standard deviations of the log-transformed responses. Except in the case of residual standard deviation, each estimate is followed by its standard error estimate and a test of significance that the log standard deviation equals zero. Figures 4-5, 4-6, and 4-7 display the estimates of these variance components. The variances are summed and stacked in these plots providing an estimate of overall uncontrolled variance in the measures. Interesting points to note regarding the variance estimates are the following:

- There was much more variability in lead concentration observed in window channel and window stool samples than any other sample type.
- Among soil sample types, random variability was greatest at the entryway and smallest at the foundation.
- The greatest relative variability in dust lead loadings was observed for air ducts, window channels, and window stools.
- The greatest relative variability in dust loading was observed for air ducts.

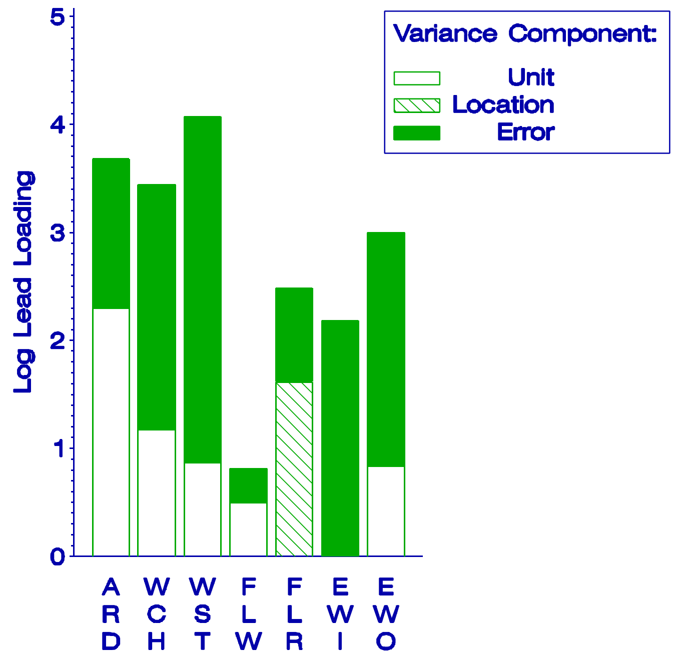


Figure 4-5. Variance component estimates from mixed model ANOVA: Lead Loading.

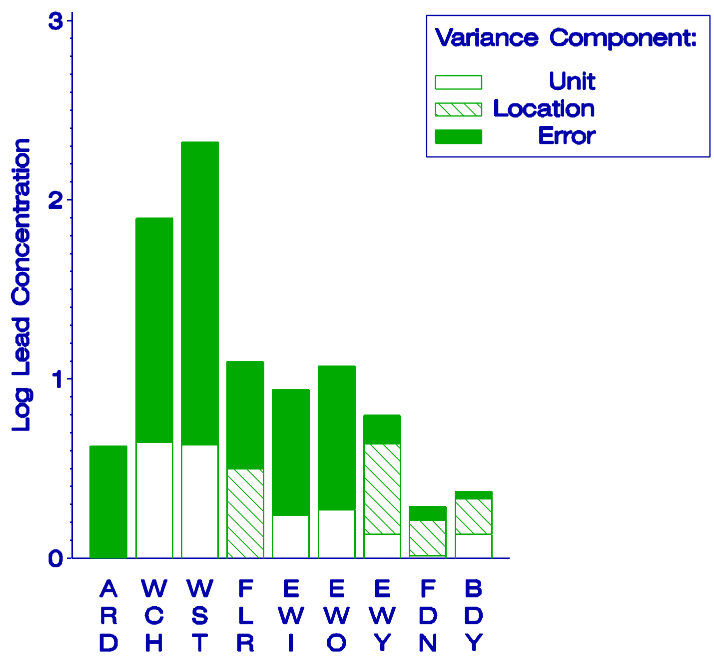


Figure 4-6. Variance component estimates from mixed model ANOVA: Lead Concentration.

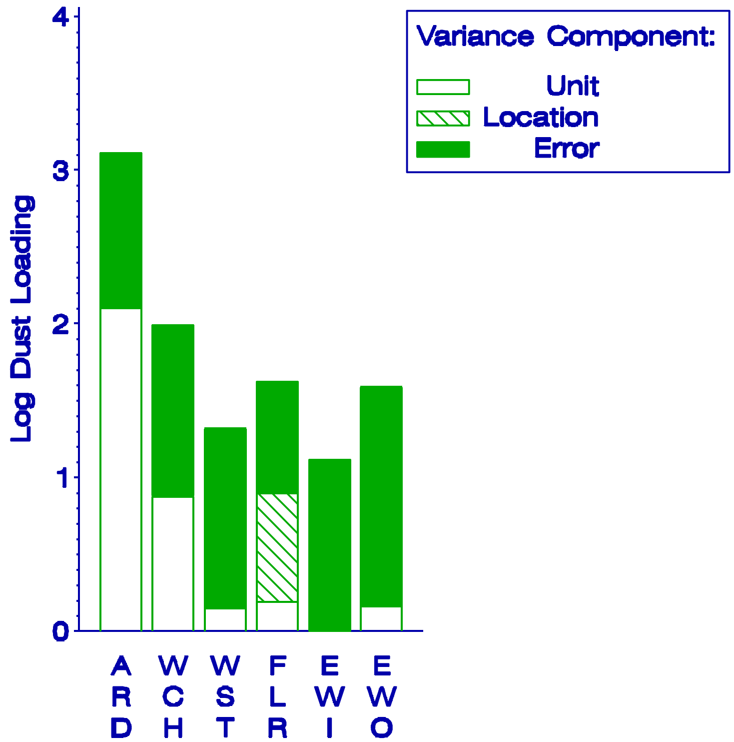


Figure 4-7. Variance component estimates from mixed model ANOVA: Dust Loading.

One of the considerations in interpreting these variance components is that different models were fit to different sample types. Therefore, for some sample types, more factors are controlled. For example, more factors were controlled in the case of foundation soil samples than any of the other soil samples; in particular, this was the only sample type for which XRF measures from the HUD Demonstration were included.

Effects of Secondary Abatement Factors

Table 4-8 displays estimates of the effects of secondary abatement factors found to be significantly associated with lead levels for at least one of the sample types. Each factor is followed by a description of the nominal level of the factor. The geometric means displayed in Table 4-4 through 4-6 should be interpreted as though levels of these factors were fixed at the nominal levels. The third column of Table 4-8 describes the deviation from nominal with which the multiplicative effects in the last three columns are associated. The fourth column of Table 4-8 displays the sample types for which each of these factors was significant. The last three columns display the estimated multiplicative effects of the stated deviations of these factors on lead loading, lead concentration, and dust loading. Two asterisks are placed in the multiplicative effect box for each response where the association was significant at the 5 percent level. As explained in Section 3, a factor was included in the model if it was found to be significant at the 10 percent level for either lead loading or lead concentration. However, in Table 4-8, all factors indicated as significant were actually significant at the 5% level - except in three cases, which are noted by single asterisks.

For example, the estimated geometric mean lead concentration on window channels in unabated houses (Table 4-5) was 851. The amount of interior abatement performed and the specific removal method used were found to be significant for this component. To estimate the average concentration in abated houses with twice as much abatement - holding all other factors at the nominal level -

Table 4-8. Multiplicative Effects of Secondary Abatement Factors

(1) Factor	(2) Nominal	(3) Deviation	(4) Sample Type	Multiplicative Effect (5) Lead Loading	(6) Lead Concentration	(7) Dust Loading
Total Interior Square Feet Abated	282 for Typical E/E 61 for Typical Removal 180 for Typical Abated	Double square feet abated	Floor (Vacuum)	(E) 0.97 (R) 1.17*	(E) 1.03 (R) 1.16**	(E) 0.95 (R) 1.03
			Window Channel	1.29	1.34**	0.96
			Window Stool	1.46**	1.22	1.19
Total Exterior Square Feet Abated	628 for Typical E/E 260 for Typical Removal 519 for Typical Abated	Double square feet abated	Window Channel	0.49**	0.59**	0.83
			Foundation	NA	0.66**	NA
Room Removal Method • Chemical Stripping • Removal/Replace • Heat Gun • Removal	 15% 15% 30% 40%	*** +10% +10% +10% +10%	Window Channel	** 0.74 1.10 1.09 1.00	** 0.95 1.11 1.27 1.00	* 0.77 0.99 0.86 1.00
Abatement Contractor • A (3 units) • B (15 units) • C (13 units) • D (4 units)	NA	NA	Air Ducts	 0.55 1.01 0.78 3.35	** 2.34 0.77 0.91 1.81	 0.24 1.36 0.83 1.87
Phase of Abatement • 1 (13 units) • 2 (13 units) • 3 (9 units)	NA	NA	Floor (wipe)	* 1.57 0.65 1.01	NA	NA

Last XRF measure at sample location during HUD demonstration	0.10 for control 0.44 for abated	Double XRF reading	Foundation	NA	1.16**	NA

*	Significant at the 10% level but not at 5% level. For groups of factors, indicates that the group as a whole is significantly related.
**	Significant at the 5% level.
***	Estimates reflect expected change due to 10% increase in specified removal method. [Sum must equal 100%.]
****	For abatement contractor and phase of abatement effects, estimates reflect difference from observed overall average for use of specific contractor or abatement performed in specific phase, e.g., lead concentrations in houses abated by contractor B were 77 percent of the (geometric) average across contractors.

multiply the geometric mean from Table 4-5 (851 μg/g) by the ratio of abated houses to unabated houses (0.98, from column four of Table 4-5) and by the estimated effect of doubling square footage abated, 1.34, displayed in Table 4-8. That is

$$851 \times 0.98 \times 1.34 = 1117.5 \ \mu g/g. \qquad (4\text{-}2)$$

One must note that this is an estimate for the "typical" abated house, which has (from the second column of Table 4-8) 180 square feet of interior abatement, and from Table 3-2, 67 percent of this abatement performed by E/E methods. To adjust this estimate for homes abated primarily by removal methods where 122 square feet were abated (61 times 2), simply multiply estimate (4-2) by the adjustment required for window channels in removal houses:

$$1117.5\ (\mu g/g) \times 1.46^{-0.078} = 855\ \mu g/g\ .$$

On floors, the impact of increased abatement was significantly different for houses abated by E/E methods compared to houses abated by removal methods. In particular, at E/E houses, there was little effect observed for increased abatement. But at houses abated by removal methods, greater lead concentrations were found in the dust in houses where more abatement was performed. Thus, an estimate of average lead concentration on the floors of houses abated primarily by removal methods with twice as much abatement as was typical for removal houses is a follows:

$$\underbrace{137 \times 1.03}_{\text{average level in typical removal house}} \times \underbrace{1.30^{-0.708} \times 1.16}_{\text{effect of twice the average abatement for removal houses}} = 136\ \mu g/g\ .$$

Estimating the effect of deviating from the nominal levels of abatement by specific removal methods is more complicated;

each of the deviations needs to be accounted for. For example, the multiplicative adjustment to lead concentration necessary to describe levels in an abated room of an abated house in which 50 percent of the removal was done with a heat gun and 50 percent was done by chemical stripping, would be

$$(0.95)^{3.5}\ (1.11)^{-1.5}\ (1.27)^{2}\ (1.00)^{-4} = 1.15.$$

The numbers in parenthesis come from the sixth column of Table 4-8, and relate to the interior removal abatement method: 0.95 for chemical stripping, 1.11 for remove/replacement, 1.27 for heat gun, 1.00 for removal. The proportion abated by removal is implicitly defined by specifying the proportion abated by the other three methods. Therefore, removal does not have to be accounted for explicitly; it is only presented here for clarity. The exponents in the equation describe the percentage of each method used as it deviates from the nominal level. The exponent 3.5 represents three and one half "deviations" from the nominal percentage of 15%, the exponent -1.5 represents negative one and one half deviations from the nominal percentage of 15%, the exponent 2 represents two deviations from the nominal percentage of 30%, and the exponent -4 represents negative four deviations from the nominal percentage of 40%.

By the method of variable screening used, every factor represented in Table 4-8 is significant for either lead loading or lead concentration. It is interesting to note that almost every significant factor had a significant impact on lead concentrations. The exceptions were phase of abatement for floor wipe samples (for which there was no concentration measured) and total interior square feet abated for window stools. Appendix C contains the detailed model fitting results listed by sample type and response.

Some important items to note regarding the effects of these secondary abatement factors are:

- Houses with large amounts of interior abatement were associated with higher lead levels on floors (see discussion below), window channels and window stools.

- Houses with large amounts of exterior abatement were found to have lower lead loadings and concentrations in window channels, and lower lead concentrations in foundation soil samples.

- Higher lead concentrations in foundation soil samples were found at houses with higher XRF/AAS readings during the HUD Demonstration.

4.2.2 Analyses of Abatement and Random Effects by Sample Type

The previous section summarized modeling results across all sample types collected. This section breaks down these modeling results into more detailed discussions for each sample type separately. In this discussion of each sample type, an effect is described as "statistically significant" if its observed significance level, or p-value, is less than 5 percent (or 0.0500). Effects with observed significance level between 5 and 10 percent are noted below, with their associated p-value, but are not declared statistically significant.

Dust Samples

This subsection presents modeling results for all locations at which dust samples were collected.

Air Ducts. There were higher levels of lead in air ducts of abated houses than in unabated houses, and levels were higher in houses abated by the E/E methods than by the removal methods. Lead loadings were almost five times higher and lead concentrations were 60 percent higher in abated homes. Lead loadings in typical E/E houses were four times higher than in typical removal houses. Concentrations were only twice as high. The above results were all statistically significant, however unabated rooms in the abated houses did not have lead levels significantly different than those in abated rooms of the same houses.

House-to-house variation was highest in air ducts for lead loadings and dust loadings. However, house-to-house variation in air duct lead concentration was negligible. This indicates that for air ducts, most house-to-house variation in air duct lead loading is due to the differences in dust levels in these houses.

A significant association was found between the observed lead concentrations in air ducts and the contractors used to perform the abatements in the HUD Demonstration.

Window Channels. There was no significant difference in lead levels observed in the window channels of abated and unabated houses. Nor were there differences between lead levels in houses abated by E/E and removal methods. However, lead loadings in unabated rooms of abated houses were about 40% as high as in the abated rooms of these houses.

There were significant differences in lead concentration and lead loading associated with use of the specific removal methods at the room level. Of the four different methods, heat gun use was associated with the highest concentrations. Total square feet abated - both interior and exterior were also statistically significant covariates. Doubling exterior square feet abated was associated with a reduction of lead loadings by half, and lead concentrations by 40 percent. Doubling interior square feet abated was associated with a 34 percent increase in lead concentration.

Houses abated by E/E methods typically had much more abatement performed than the houses abated primarily by removal methods. The estimates provided are adjusted for this potential confounding factor. A typical interior removal house is defined as having 61 total square feet abated indoors; for a typical interior E/E house, 282 square feet of interior abatement is assumed. These numbers are based on a regression of (log) square feet abated on the percent abated by E/E methods.

Window channels and window stools were associated with the greatest total variation in lead levels. The variation was particularly notable for lead concentrations (see Figures 4-5 and 4-6).

Window Stools. Neither differences between lead loadings nor lead concentrations in abated and unabated houses was statistically significant. Although geometric mean lead loadings were about twice as high on window stools of abated houses than they were in unabated houses, there was also large variability observed in the results. Lead loadings were 2.5 times as high on window stools in the average E/E house as in the average removal house. Lead concentrations were about 1.8 times as high in these houses. These results were not significant at the 5% level. There were no significant differences in dust loadings between these houses. Although lead levels were about a third lower in unabated rooms of abated houses, the differences were not statistically significant.

Floor (Wipe). Abatement method was the only abatement effect which was estimated for floor lead loadings from wipe samples. Although levels were slightly lower in E/E houses, no significant differences were found.

Random house-to-house variation was statistically significant for this sample type, but it was moderate in magnitude. The estimated residual log standard deviation was smallest for this sample type, but this requires some explanation. By design, the floor wipe samples were taken to compare with the floor vacuum samples (see Section 6). Two side-by-side samples were taken per abated house. Thus, the residual log standard deviation is really a measure of side-by-side sample variability. This is in contrast with the other dust sample types for which the two samples per house were often taken from different rooms.

The houses abated in the HUD Demonstration in Denver were abated in three different phases according to the magnitude of abatement required. The worst houses were abated first. Table 4-8 indicates higher lead levels were found in homes abated in the first phase than in the second phase, with levels in the third phase about average.

Floor (Vacuum Samples). About twice as many floor (vacuum) samples were taken as for any other sample type in the study. No statistically significant contrasts were observed for the primary abatement effects, but there were higher levels of dust on the floors of abated houses (p=.089) contributing to higher, but not significantly higher (p=.105) lead loadings in these houses. Lead loadings in houses abated by E/E methods were twice as high as in removal houses (p=0.53), due to a combination of slightly higher lead concentrations and slightly higher dust loadings in these houses.

There was a significant relationship observed between the total square feet abated indoors and lead concentration (see Table 4-8). But this relationship depended on whether the abatement was primarily E/E, or primarily removal. Houses where a large amount of abatement was performed primarily by removal methods were associated with significantly higher lead levels. Doubling square feet abated indoors was associated with about 16% higher concentrations and 17% higher lead loadings. In E/E houses this difference was only about 3% for concentration and negative 3% for loading. These differences were not statistically significant.

There were negligible random house-to-house differences in both lead loadings and lead concentrations for floor samples. Although not significant, there were differences present in dust loadings. There were significant room-to-room differences within houses for lead loadings, lead concentrations, and dust loadings. It is interesting to note that in Figure 4-5, the room-to-room variance component alone for vacuum floor samples is greater than the estimated total variance for the corresponding wipe samples. (In the figure, the room-to-room variance component is represented by "Location"). Another practical note illustrated by this figure is that the residual log standard deviation estimate (the within-room component) for vacuum floor samples is larger than that for wipe floor samples. However, in some cases, repeated vacuum floor samples taken within the same room were taken from different locations within the room, as opposed to side-by-side as were the wipe floor samples. Thus, this standard deviation includes within-room variation, whereas, the floor wipe residual standard deviation does not. A complete discussion of the wipe and vacuum sample comparisons is presented in Section 6.

Interior Entryway. There was no significant difference observed in lead levels among the three categories of homes. Nor was there a significant unabated room effect in abated homes.

Perhaps the most interesting thing to note about these samples is the corrected geometric mean lead loading. The estimated lead loading for interior entryways in unabated houses is 12 times higher than that for regular floor (vacuum) samples. This difference is due to only a 33% difference in lead concentration, but a nine-fold difference in dust loading.

Although it was not statistically significant, there was random house-to-house variation in lead concentration, but not in lead loading or dust loading. Residual log standard deviation was relatively large for lead loading. The residual variation primarily represents differences between entryways within the same house.

Exterior Entryway (Dust). Although not statistically significant, there were differences in lead loading in the dust outside the entryways sampled. Lead loadings in abated houses were more than twice as high ($p=.07$) as outside unabated houses. These differences were due to significantly higher dust levels at the abated houses ($p = .03$), not to higher concentrations of lead in this dust. There was no difference observed in levels abated by different methods.

There was random house-to-house variation ($p=.076$) in lead loading at exterior entryways. This was due to random variations in lead concentration ($p=.097$), not to dust loading variations. Residual log standard deviation was very large for lead loading (as for the interior entryways).

It is interesting to note that the average lead concentrations for interior and exterior entryway samples at unabated houses were almost identical. Differences between abated houses and unabated houses were only observed on the exterior.

Soil Samples

The strongest relationships between lead concentrations and abatement were seen in soil samples. Lead concentrations were higher outside abated houses than outside unabated houses. Controlling for all covariates, lead concentrations outside unabated houses were highest at the entryway. There was significant side-to-side variation for each of the measures and significant house-to-house variation for boundary samples. The greatest total variance was observed for entryway samples. Side-by-side variation was largest at the entryways.

Entryway (Soil). Although not statistically significant, the soil outside entryways of abated houses had average lead concentration about 50% higher than outside unabated houses ($p=.087$). Average levels at unabated houses were estimated at 126 µg/g. Random house-to-house variability in entryway soil lead concentrations was not statistically significant, but there were significant random differences between levels observed at different entryways to the same houses.

Boundary Soil. Soil concentrations at the boundaries of unabated houses were 86 µg/g on average. At abated houses, concentrations were more than 60% higher. This was very significant. Differences observed between levels at houses abated by different methods were not significant.

There was significant random house-to-house variation, and significant side-to-side variation.

Foundation Soil. In soil, the greatest difference between lead concentrations in abated houses and unabated houses was seen at the foundation. Lead concentrations were 82 percent higher in the soil near foundations of abated houses than at unabated houses. This difference was statistically greater than the corresponding difference at the boundary, supporting claims that contrasts may at least in part be due to the presence of lead-based paint at the abated houses.

Differences observed between levels in houses abated by different methods were not significant. Also, lead concentrations were significantly lower in the foundation soil of houses with more than average abatement performed on the exterior. Houses where twice as much abatement was performed outside were found to have 34% lower lead concentrations.

House-to-house differences were not significant, but side-to-side variation was significant. There was a strong correlation between the foundation soil lead concentrations observed in the CAP Study and the XRF/AAS measures taken during the HUD Demonstration. This relationship is displayed in Figure 4-8. In this figure, lines of best fit are drawn separately for control and abated houses. Although lead concentrations are higher on average in abated houses than in unabated houses, there is evidently a similar relationship between lead concentration and XRF measures for both groups of houses.

4.2.3 Analysis of Non-Abatement Factors

Table 4-9 displays the effects of non-abatement factors found to be significantly associated with lead levels. These included substrate, questionnaire responses, age of the house, etc. The format of the table is similar to Table 4-8 with an initial column added to distinguish between classes of related factors. These classes include substrate, cleanliness, occupation, activities, ownership, and sampling deviations.

None of these factors was found to be significant for more than three sample types. For every sample type, lead loading or

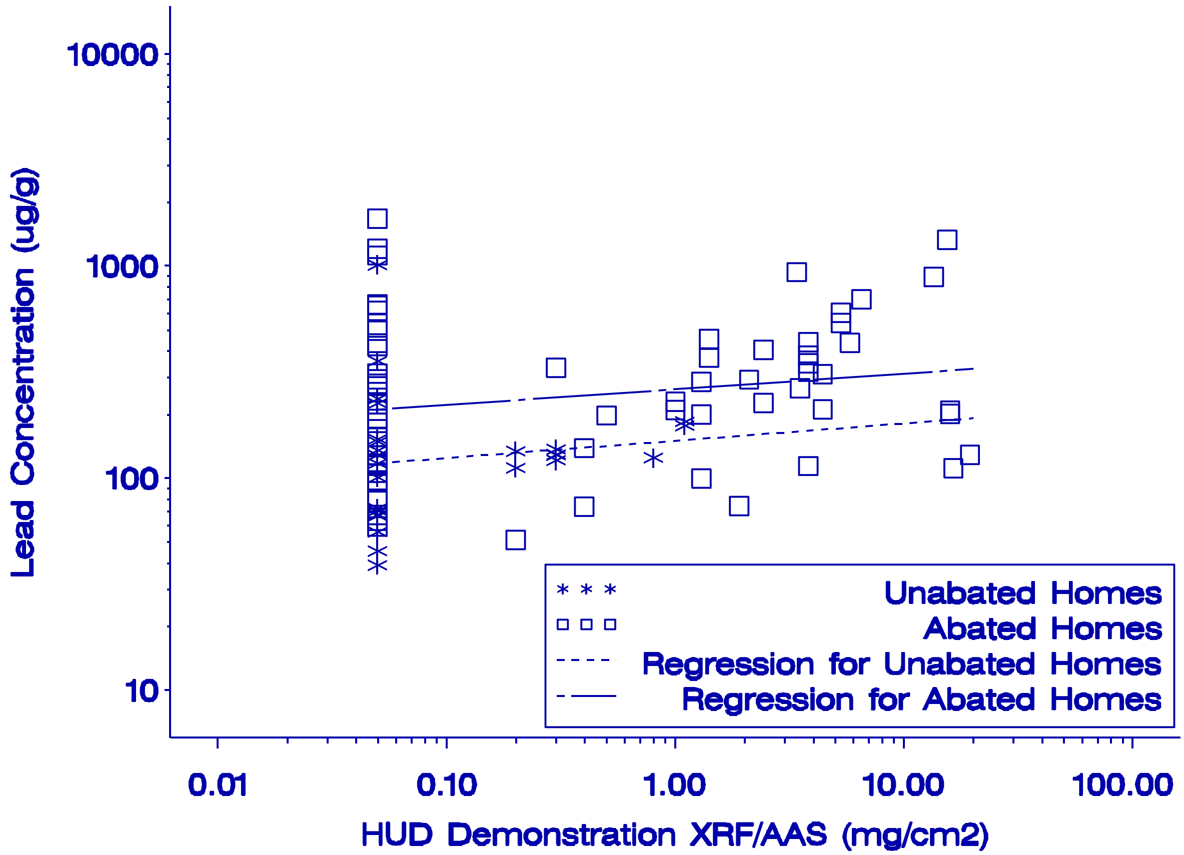


Figure 4-8. **Foundation soil lead concentration vs. HUD Demonstration XRF/AAS levels.**

lead concentration was observed to be significantly associated with at least one of these factors at the 10 percent significance level.

The substrate from which samples were collected was a significant factor for window channels, floors, and interior entryways. This is displayed in Figure 4-9 for floors with a box and whisker plot. (The same format is used in this plot as was used in Section 2 plots.) The corrected geometric means presented in Tables 4-4 through 4-6 are to be interpreted as the mean across substrate weighted by their observed relative frequency in the study. Table 4-9 indicates the distribution of the substrates encountered in this study. For regular floor samples, carpet and linoleum were most prevalent. For interior entryways, carpet was most often observed. Wood was the most prevalent substrate in window channels. Table 4-9 presents the ratio of levels observed for each substrate relative to the average.

In general, on the floors (including interior entryways), carpet had higher dust loadings than any of the other sample types. (Although the dust loadings were highest on concrete, only four samples were collected on that substrate.) Lead concentrations were typically highest on wood (excluding concrete) for all of the sample types where substrate was found to be significant. Lead loadings were higher on wood than on carpet for regular floor samples, but the opposite was true at the entryways. The condition of the substrate was also significant, with damaged, peeling, and chalking substrates noted for higher lead concentrations.

Sampling deviations were also significant factors. On some air ducts, the cover was not removable and so a sample was taken from the cover. These samples had one quarter of the dust loading and lower lead concentrations as compared with regular samples taken from inside the air ducts. For some window stool and some window channel samples a small nozzle was used on the end of the vacuum sampler. Lead concentrations and dust loadings

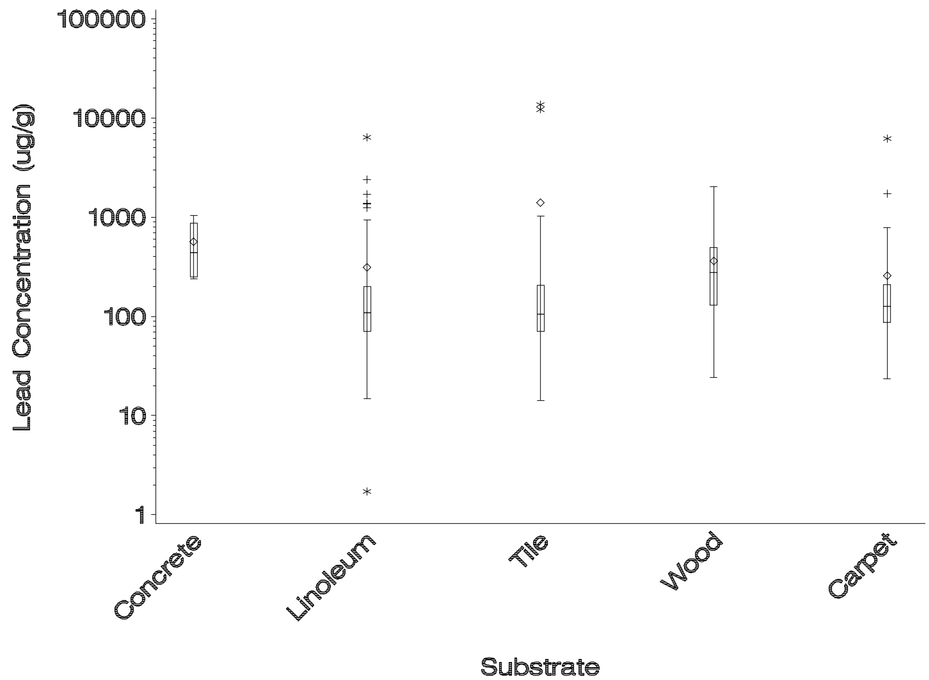


Figure 4-9. Floor dust lead concentration vs. substrate.

Table 4-9. Multiplicative Effects of Non-Abatement Factors

Type of Explanatory Variable	Factor	Nominal[1,2]	Deviation[2]	Sample Type	Multiplicative Effect: Lead Loading	Multiplicative Effect: Lead Concentration	Multiplicative Effect: Dust Loading
Substrate	Substrate Type	Observed average across substrates		Window Channel	*	*	*
			Wood (44)		1.94	1.67	1.14
			Concrete (1)		0.93	6.45	0.15
			Metal (33)		0.62	0.55	1.14
			Plastic (5)		0.07	0.37	0.19
				Floor (Wipe)	*	NA	NA
			Concrete(1)		24.19		
			Linoleum(38)		0.84		
			Tile(8)		0.66		
			Wood(18)		1.44		
				Floor (Vacuum)	*	*	*
			Carpet (84)		2.22	0.79	2.76
			Concrete (4)		27.52	3.44	8.96
			Linoleum (85)		0.31	0.87	0.35
			Tile (20)		0.27	0.94	0.29
			Wood (40)		3.22	2.04	1.63
				Entryway (Interior)	*		*
			Carpet (47)		2.79	0.99	2.89
			Linoleum (26)		0.43	0.93	0.43
			Plastic (2)		0.02	0.76	0.02
			Tile (7)		0.08	1.07	0.07
			Wood (8)		0.97	1.33	0.77
	Substrate Condition	Good (82)		Air Duct	*	*	*
			Damaged (1)		41	1.5	28
			Peeling (3)		28	6.7	2.5

[1] Weighted by observed relative frequencies.
[2] Number in parentheses represents the number of samples collected in this manner.
* Significant at the 10% level. For group of factors, * indicates that the group as a whole is significant.

Table 4-9. (Continued)

Type of Explanatory Variable	Factor	Nominal[1,2]	Deviation[2]	Sample Type	Multiplicative Effect		
					Lead Loading	Lead Concentration	Dust Loading
		Good (48)		Window Channel		*	
			Chalking (2)		1.78	3.16	0.56
			Peeling (33)		3.06	2.71	1.17

[1] Weighted by observed relative frequencies.
[2] Number in parentheses represents the number of samples collected in this manner.
* Significant at the 10% level. For group of factors, * indicates that the group as a whole is significant.

Table 4-9. (Continued)

Type of Explanatory Variable	Factor	Nominal[1,2]	Deviation[2]	Sample Type	Multiplicative Effect		
					Lead Loading	Lead Concentration	Dust Loading
Cleanliness	Frequency of vacuuming uncarpeted floors	12 times/mo	6 additional times/mo	Floor (Vacuum)	1.02	1.03*	1.00
				Entryway (Interior)	1.06*	1.06*	0.99
				Entryway (Exterior)	1.00	1.05*	0.96*
	Frequency of wet mopping uncarpeted floors	12 times/mo	6 additional times/mo	Air Duct	0.97	0.98*	0.98
	Frequency of window sill dusting	1 time/mo	1 additional time/mo	Air Duct	0.99	1.03*	0.96
Occupation	Wearing home work clothes from an occupation with potential lead contamination	No	Yes	Window Stool	2.96*	1.45	2.01*
				Entryway (Soil)	NA	0.66*	NA
	Resident employed in welding occupation	No	Yes	Floor (Vacuum)	9.08*	3.72*	2.49*
				Foundation	NA	1.82*	NA
	Resident employed in salvage occupation	No	Yes	Boundary	NA	1.13*	NA

[1] Weighted by observed relative frequencies.
[2] Number in parentheses represents the number of samples collected in this manner.
* Significant at the 10% level. For group of factors, * indicates that the group as a whole is significant.

Table 4-9. (Continued)

Type of Explanatory Variable	Factor	Nominal[1,2]	Deviation[2]	Sample Type	Multiplicative Effect		
					Lead Loading	Lead Concentration	Dust Loading
	Resident employed in paint removal occupation	No	Yes	Boundary	NA	0.40*	NA

[1] Weighted by observed relative frequencies.
[2] Number in parentheses represents the number of samples collected in this manner.
* Significant at the 10% level. For group of factors, * indicates that the group as a whole is significant.

Table 4-9. (Continued)

Type of Explanatory Variable	Factor	Nominal[1,2]	Deviation[2]	Sample Type	Multiplicative Effect: Lead Loading	Multiplicative Effect: Lead Concentration	Multiplicative Effect: Dust Loading
Activities	Frequency of removing paint at home	Never in last 6 months	1 additional time per 6 months	Entryway (Interior)	1.06	1.10*	0.97
				Foundation	NA	0.85*	NA
	Frequency of pipe or electrical component soldering	Never in last 6 months	1 additional time per 6 months	Boundary	NA	1.32*	NA
Ownership	Number of children (7-17)	0	1 additional child	Entryway (Interior)	0.64*	0.81*	0.78*
	Ownership of home	Owner	Renter	Foundation	NA	0.32*	NA
				Floor (Wipe)	0.58*	N/A	N/A
	Number of months at residence	18	1 month longer	Foundation	NA	0.94*	NA
	Year house was built	1943 for unabated 1926 for abated	10 years newer	Entryway (Soil)	NA	0.90*	NA
				Foundation	NA	0.77*	NA
				Boundary	NA	0.83*	NA
	Number of Pets	0	1 additional pet	Floor (Vacuum)	1.02	0.82*	1.27*

[1] Weighted by observed relative frequencies.
[2] Number in parentheses represents the number of samples collected in this manner.
* Significant at the 10% level. For group of factors, * indicates that the group as a whole is significant.

Table 4-9. (Continued)

Type of Explanatory Variable	Factor	Nominal[1,2]	Deviation[2]	Sample Type	Multiplicative Effect		
					Lead Loading	Lead Concentration	Dust Loading
Sampling Deviations	Sampling Location	Inside Air Duct (48)	Cover of Air Duct (38)	Air Duct	0.18*	0.78	0.26*
	Sampling Device	Large Nozzle (60)	Small nozzle (26)	Window Channel	3.47*	1.56	2.14*

[1] Weighted by observed relative frequencies.
[2] Number in parentheses represents the number of samples collected in this manner.
* Significant at the 10% level. For group of factors, * indicates that the group as a whole is significant.

were greater for these samples than for those collected with the large nozzle.

Older homes had higher soil lead concentrations than newer homes for all three soil sample types. This is demonstrated for boundary samples in Figure 4-10. Abated and unabated homes are identified in this figure with a different regression line plotted for each class of homes describing the relationship between house age and lead concentration in the soil. As was the case for XRF measures, average lead concentration is higher in the abated houses than in the unabated houses, but the relative increment due to age is similar in both groups of houses.

Houses where pipes or electronic parts were soldered within the last 6 months had 33% higher lead concentrations. Other significant factors were less intuitive. For instance, lower lead concentrations were observed in boundary soil of houses where residents are employed in a paint removal occupation. For completeness, all factors significant at the 10% level are represented, even if they do not appear to be intuitive.

Although past studies (EPA, 1995b) have documented seasonal variation in environmental-lead levels, data was collected for this study during an interval of five weeks during March and April 1992. Therefore, it was not necessary to control for seasonal variations in comparing abated to unabated houses. However, in comparing average levels observed in this study to those in other studies it might be important to compare the times of year in which sampling was performed.

Some caution needs to be applied in the interpretation of significant effects. For example, there were two houses in which the resident interviewed stated that the uncarpeted floors were vacuumed every day. In these houses, lead concentrations were significantly higher in exterior entryway samples at these houses. This relationship is portrayed in Figure 4-11. Whereas the frequency of vacuuming uncarpeted floors was found to be significantly associated with lead concentrations for these sample types for the houses in the study, when the two houses

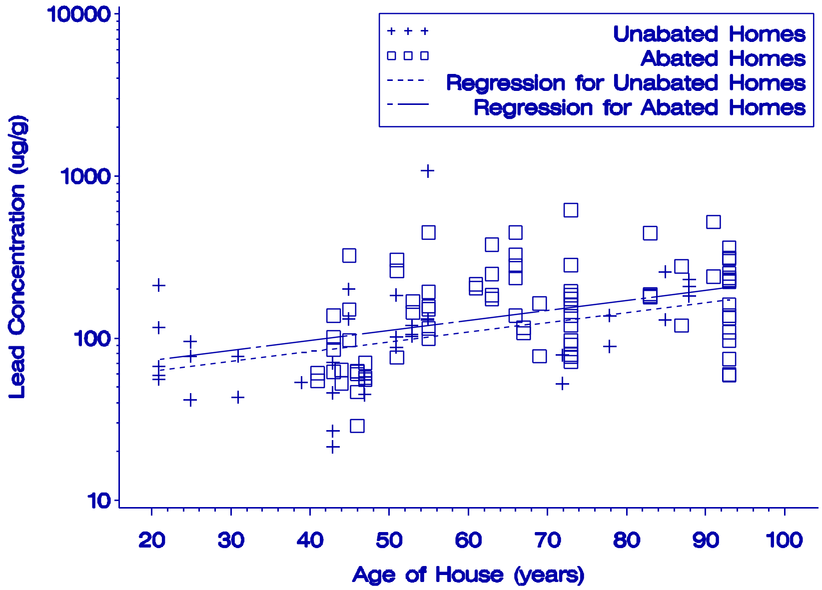


Figure 4-10. Boundary soil lead concentration vs. age of house.

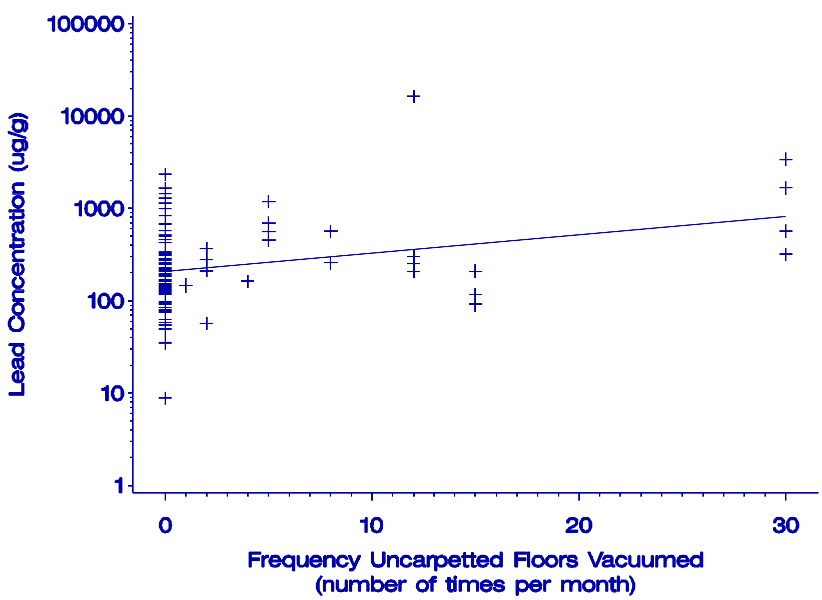


Figure 4-11. Exterior entryway dust lead concentration

discussed above were excluded the factor was not observed to be significant. However, in the results presented, data from these two houses were included.

There were three houses at which a resident was employed in an occupation where welding was performed. Lead concentrations and dust loadings were significantly higher at these houses than at others. Two of these were abated and one was an unabated house.

4.2.4 <u>Non-Abatement Effects by Sample Type</u>

<u>Dust Samples</u>

Air Ducts. One hundred nine (109) air duct samples were collected. Two of the 109 air duct samples were taken from baseboard-type heating elements and two others were taken from cold-air returns. There were differences between results of these and other types of samples. To avoid making unsubstantiated conclusions about the impact of these deviations and to simplify interpretation, these four samples were deleted from the analyses. Due to common difficulties in removing covers from air ducts, 46 of 109 samples were taken from the exterior fins or grates covering the air ducts. The remaining 59 samples were taken from inside the air ducts. This had a significant impact on the results. The substrate condition was also observed to have a significant effect. Table 4-9 presents estimates of these effects.

Lead loadings were substantially lower in samples taken from the exterior grates. This was mainly due to significantly lower dust loadings, but concentrations were also slightly lower (though not significantly lower). One air duct was damaged and three air ducts had peeling substrates. Lead levels were significantly higher on the damaged and peeling substrates.

Lead concentrations were lower in houses where there was frequent wet-mopping of uncarpeted floors. In houses where the window stools were frequently dusted, there were higher concentrations in the air ducts.

Window Channels. Substrate and condition of substrate were important factors associated with lead levels in window channels. Thirty-three (33) of the channels were made of metal; 44 were made of wood. Differences in lead concentrations and lead loadings on these were significant. Lead loadings were almost 40% lower than average on metal. Conditions of these substrates were primarily either good or peeling. These differences were shown to have an association with lead concentrations. On peeling surfaces, concentrations were almost three times as high as on channels which were intact.

Twenty-seven (27) percent of the window channel samples were taken with the small nozzle attached to the vacuum. Lead loadings were estimated to be three and one-half times higher in these samples.

Window Stools. Significantly higher lead loadings were observed in houses where a resident wore work clothes home from an occupation with potential lead exposure. Lead concentrations in these houses were not significantly higher, but dust loadings were higher.

Interior Entryway. The most influential variable for lead loading appeared to be substrate, with highest loadings observed in samples taken from carpets. Most of the samples were taken from carpet and linoleum with fewer taken on tile and wood floors. Lead loadings were about six times higher on carpet than on linoleum; three times higher on carpet than on wood; and more than 30 times higher on carpet than on tile. The differences were attributed to greater levels of dust retained by the carpet, since there were no significant differences in concentrations among these substrates.

There were somewhat higher lead loadings and concentrations in homes where there was more frequent vacuuming of uncarpeted floors. The difference in lead concentration was about 6 percent for a 50 percent increase in frequency of vacuuming. Higher concentrations were observed in houses where paint removal was recently done. Lower loadings and concentrations were observed in houses where there were more children between the ages of 7 and 17.

Exterior Entryway (Dust). Aside from abatement, only frequency of vacuuming uncarpeted floors was found to be significantly related to levels of lead in the dust outside the entryways to these homes. Lead concentrations were found to be higher in houses where vacuuming of uncarpeted floors was more frequent. Dust levels were lower in these houses. These two relationships combined to yield no association between the factor and lead loading.

Floor (Wipe). Substrate was found to be an important determinant in lead loading for wipe samples. Most samples were collected from linoleum (38) and wood (18) floors. Loadings were about 50 percent higher on wood than on linoleum. (Lead loadings on wood were also higher than on linoleum for floor samples collected by vacuum.) Also, rented homes had lead loadings on floors 42 percent lower than those in owner-occupied homes.

Floor (Vacuum). Perhaps the most significant factor associated with floor lead levels was substrate. Most of the samples were taken on carpet (84), linoleum (85), wood (40), and tile (20). Of these, dust loading was greatest on carpets. Lead concentrations were similar on carpet, linoleum, and tile, but on wood they were over two times as large. Hence the highest lead loadings (excluding four samples taken on concrete) were on wood. Lead loadings were about 50 percent higher on wood than on carpet, and were much lower on linoleum and tile.

In houses where uncarpeted floors were vacuumed more frequently, there were higher lead concentrations. Homes in which a resident was employed in welding had lead concentrations almost four times as large as in homes which did not. In those same houses, dust loadings were more than twice as high, contributing to lead loadings more than nine times as great.

The presence of pets was also found to be significantly related with the concentrations of lead in the dust on the floors of these houses. Lead concentration was 18 percent lower and dust loading was 27 percent higher in these houses. Lead loading was about the same. Thus, owning pets may increase the amount of dust present without significantly influencing the amount of lead.

Soil Samples

Entryway Soil. House age was found to be related to lead concentration in soil outside the entryways of these houses. Lead concentrations were lower in newer houses. The relative difference in soil lead concentration at the entryways of these houses was about 10 percent for every ten years difference in age.

There was also a difference observed between lead concentrations in entryway soil at houses where a resident brought work clothes home from an occupation with potential lead contamination. Homes with these types of residents had lead concentrations about 34 percent lower.

Foundation Soil. Several factors were significantly associated with lead concentrations in foundation soil. Most of the significant non-abatement factors were related to ownership of the home. Older houses had higher concentrations. A ten-year difference in age was associated with a difference of 23 percent in lead concentrations near the foundation. However, lead levels were lower in houses where the residents have lived longer since abatement. A house occupied one month longer than the nominal period of 18 months had an estimated 6% lower lead level. Controlling for the other factors, lead concentrations around homes rented by their residents were only about a third as high as around those homes owned by their residents.

Another factor found to be significantly associated with lower lead concentrations was recent paint removal at the house.

Also, lead concentrations were almost twice as high around houses where a resident was employed in a welding occupation.

Boundary Soil. Lead concentrations in boundary soil were significantly associated with the age of the house. An increase in age of 10 years was associated with an increase in lead concentration of about 20 percent. From Figure 4-10, it is apparent that logarithm of lead concentrations increased fairly linearly with age of house.

Three homes were observed in which a resident was employed in an occupation involving paint removal. In these homes, lead concentration was significantly lower (60 percent lower). There was also a significant association found between lead concentration in boundary soil and the frequency with which pipes or electronic parts were soldered in the last 6 months. Levels were significantly higher in houses where soldering activity occurred. Finally, houses where a resident was employed in an occupation involving salvage had higher boundary lead concentrations.

5.0 CORRELATIONS

Section 4 summarized the relationship between lead levels and various abatement, sampling and other factors by sample type. Here we discuss correlations of lead levels between the various sample types after correction for the estimated effects of the factors discussed in Section 4. Thus, these correlations should be interpreted as relationships between different sample types above and beyond that which are explained by things like abatement, age of house, cleanliness measures, and other factors included in the models.

This analysis involves examining correlation matrices and scatterplot matrices. The primary data used to examine these relationships are the estimated random house (house) effects and the estimated random location-within-house effects. Both of these random effects are estimated after controlling for the estimated fixed effects in the model for each sample type.

5.1 BETWEEN-HOUSE CORRELATIONS

The correlation matrix of random house-to-house differences in lead loading is presented in Table 5-1. To locate a correlation of interest, locate the row corresponding to the first sample type and the column corresponding to the second sample type. Correlation information for the two sample types is presented in the corresponding box. Within each box, three values are presented:

- **Top value:** Correlation coefficient between the logarithms of the geometric house means,

- **Middle value:** Degrees of freedom used in calculating the correlation coefficient, and

- **Bottom value:** Observed significance level of the test of the hypothesis of no correlation (correlation coefficient equal to zero).

Table 5-1. Correlations* Among Sample Types for Between-House Random Effects: Lead Loading

	Air Duct	Window Channel	Window Stool	Floor (Wipe)	Entryway Exterior (Dust)
Air Duct		.16 33 .37	.13 37 .43	.25 21 .26	.41 36 .01
Window Channel			.56 41 .00	-.08 25 .68	.12 40 .43
Window Stool				-.03 27 .87	.09 45 .55
Floor (Wipe)					.44 27 .02
Entryway Exterior (Dust)					

* Top number is estimated correlation; middle number is degrees of freedom; and bottom number is significance level.

Only the upper right-hand half of the matrix, above the shaded diagonal, is filled in since the lower left-hand half of the matrix would contain redundant information.

When controlling for the fixed effects, degrees of freedom for the estimation of correlation are specified to estimate the fixed effects. This was accounted for in the significance levels and the degrees of freedom displayed in the correlation tables.

The following method was used to calculate degrees of freedom for estimating the house-level correlation of two sample types, A and B:

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1. Let $m_{A,B}$ denote the number of houses from which samples of both types were taken, and

2. Let f_i denote the number of house-level fixed effects in the model fit for sample type i (i=A,B).

3. $df_{A,B} = m_{A,B} - \max(f_A, f_B) - 2$.

In most cases there were at least 30 degrees of freedom. Estimates of correlations with floor wipe samples had fewer degrees of freedom because the samples were only taken in the abated houses.

Some sample types are not represented in the house-level correlation analysis. This is because in some cases the restricted maximum likelihood (REML) estimates of the random house-to-house differences were negligible after controlling for the fixed effects. This happened in the case of interior entryway lead loadings, vacuum floor lead loadings and concentrations, air duct concentrations, and interior entryway dust loadings.

The lead loading random house effect estimates are presented graphically in Figure 5-1. This figure is a scatterplot matrix,

or a collection of bivariate plots organized into matrix form.
As with the correlation matrix, to locate a plot of interest,

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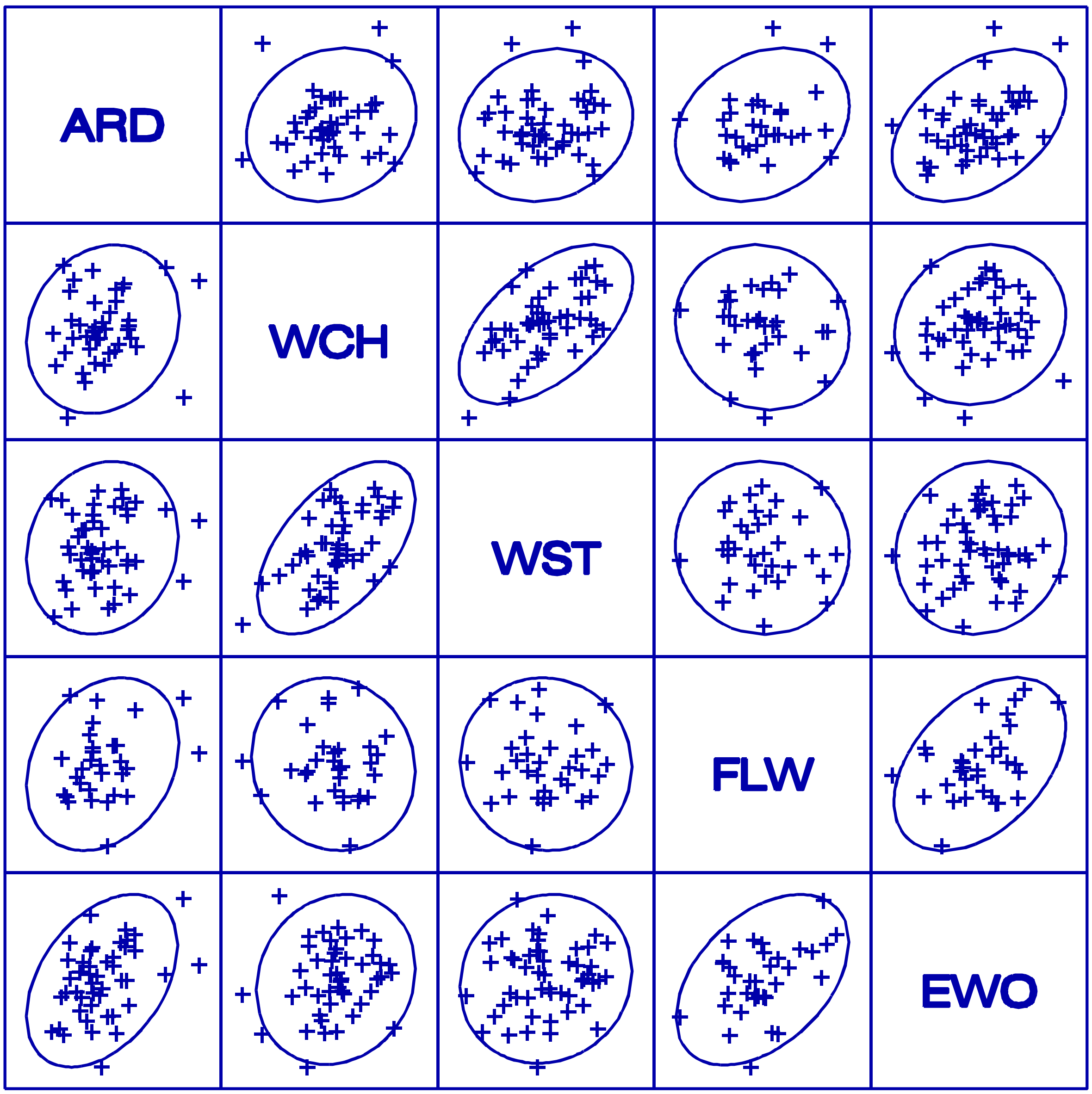

Figure 5-1. **Scatterplot matrix of unit-level random effects for different sample types: lead loading ($\mu g/ft^2$).**

identify the row associated with one sample type and the column associated with the other sample type. The plot is presented in the corresponding box. Within each box, the horizontal axis represents increasing values of the column variable on a logarithmic scale. Similarly, the vertical axis represents increasing values of the row variable on a logarithmic scale. The abbreviations employed on the diagonal to identify the different sample types are defined in Table 1-4.

The ellipse plotted in each box of Figure 5-1 is the ellipse that contains 95% of the probability associated with the estimated bivariate normal distribution for the plotted data. The narrower the ellipse, the stronger the correlation between the two sample types. If the ellipse is oriented from the lower left-hand corner of the box to the upper right-hand corner of the box, the sample types are positively correlated. If, on the other hand, the ellipse is oriented from the upper left-hand corner of the box to the lower right-hand corner of the box, the sample types are negatively correlated.

Table 5-2 contains house-to-house correlation estimates for lead concentrations; Table 5-3 provides the same for dust loading. Figure 5-2 is the analog to Figure 5-1 for lead concentrations; Figure 5-3 provides the same information about dust loadings.

There were several indications of a positive house-level correlation between different sample types. No significant negative correlations were observed. Thus, unexplained (not accounted for by the models) differences between lead and dust levels in different houses appear to be similar for certain pairs of sample types.

The strongest correlation in lead loadings was observed between window channels and window stools. The estimated

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correlation was 0.56 with 41 degrees of freedom. This was highly significant. Examining Figures 5-2 and 5-3 reveals that this

Table 5-2. Correlations* Among Sample Types for Between-House Random Effects: Lead Concentration

	Vacuum				Soil		
	Window Channel	Window Stool	Entryway Interior	Entryway Exterior	Entryway	Foundation	Boundary
Window Channel		.40 41 .01	.27 40 .08	.26 40 .10	.23 41 .13	.07 24 .72	.15 39 .35
Window Stool			.07 44 .63	-.06 45 .70	.18 46 .22	.12 29 .53	.38 44 .01
Entryway Interior				.25 43 .09	.29 44 .05	.26 28 .16	.22 43 .15
Entryway Exterior					.18 45 .22	.32 28 .08	-.12 43 .44
Entryway						.29 29 .11	.56 44 .00
Foundation							.09 29 .93
Boundary							

* Top number is estimated correlation; middle number is degrees of freedom; and bottom number is significance level.

Table 5-3. Correlations* Among Sample Types for Between-House Random Effects: Dust Loading

	Air Duct	Window Channel	Window Stool	Floor (Vacuum)	Entryway Exterior (Dust)
Air Duct		-.32 33 .06	.03 37 .88	.12 37 .45	.33 36 .04
Window Channel			.34 41 .02	.17 38 .28	.01 40 .96
Window Stool				.27 43 .07	.15 45 .30
Floor (Vacuum)					.33 42 .03
Entryway Exterior (Dust)					

* Top number is estimated correlation; middle number is degrees of freedom; and bottom number is significance level.

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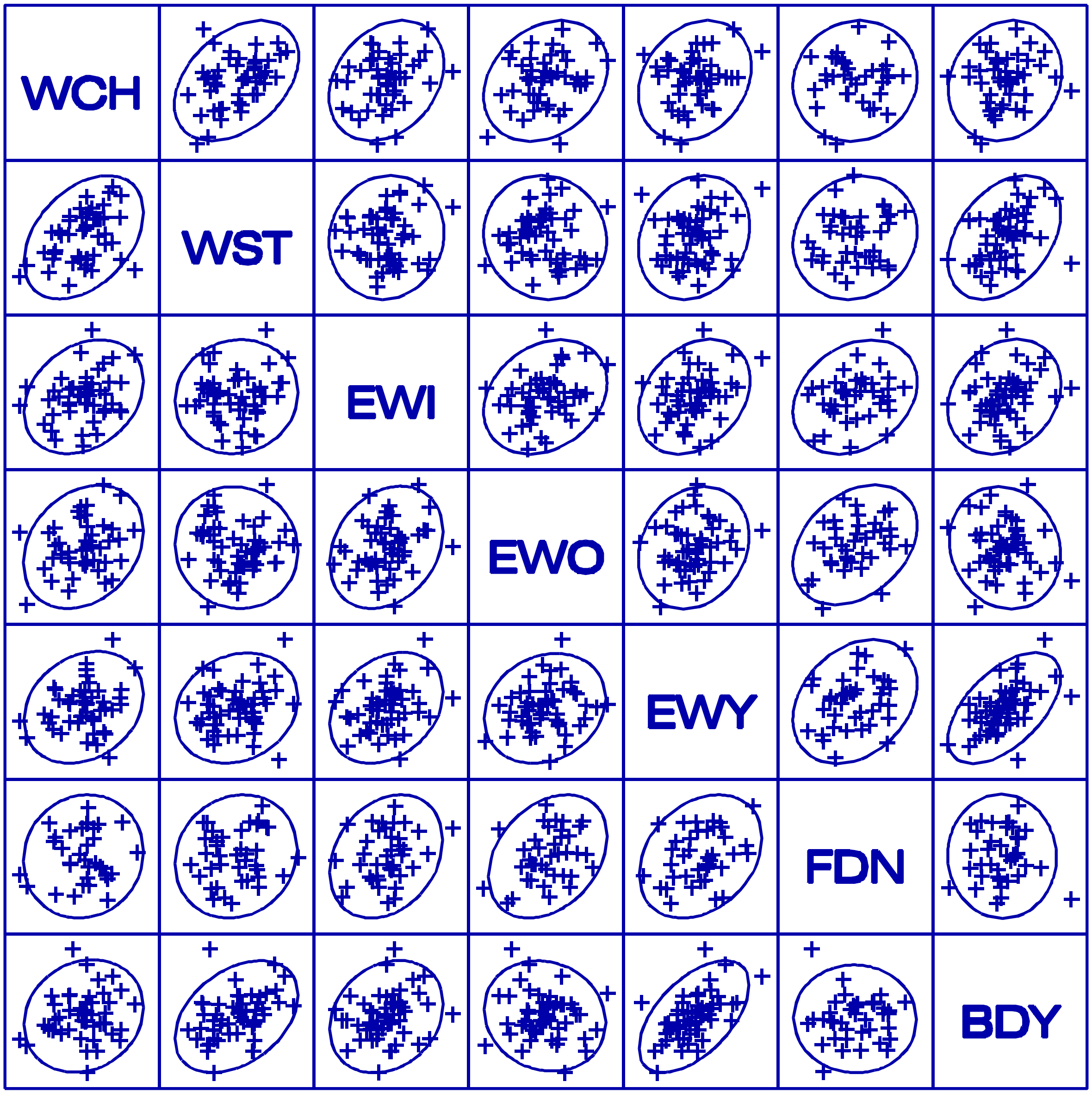

Figure 5-2. **Scatterplot matrix of unit-level random effects for different sample types: lead concentration (μg/g).**

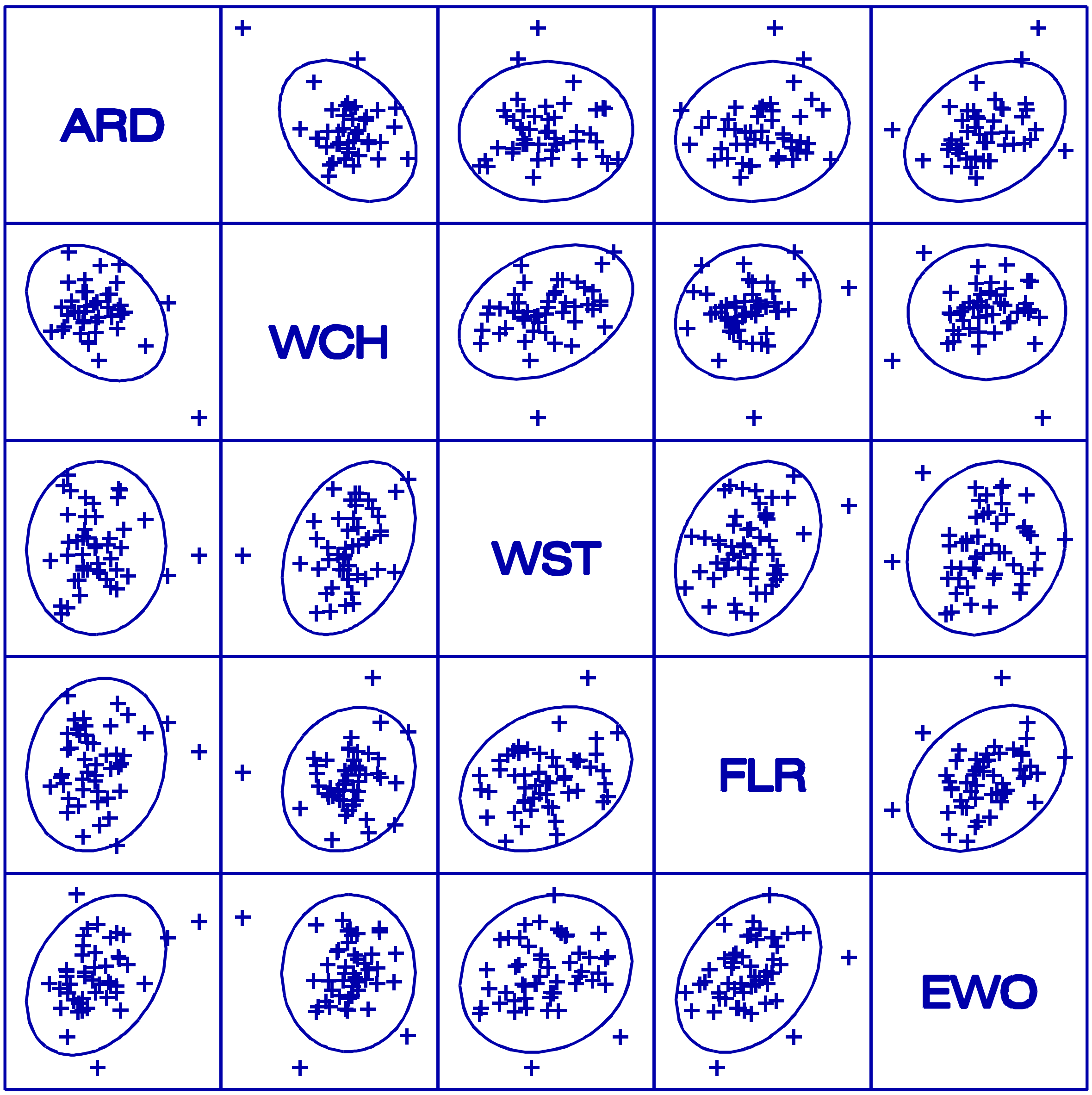

Figure 5-3. Scatterplot matrix of unit-level random effects for different sample types: dust loading (μg/g).

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relationship is due to positive correlations in both lead concentrations and dust loading.

Significant correlation was observed for lead loadings between air duct and exterior entryway lead loadings. The house-to-house variation in air duct lead concentrations was negligible (refer to Table 4-5). However, there was significant correlation observed in dust loadings for these two sample types. That is, at houses where much dust was found at the exterior entryways, there was also much dust found in the air ducts. Exterior entryway dust lead loading was also significantly correlated with floor lead loading collected with wipes.

There were also significant correlations observed in soil lead concentrations at different property locations (Table 5-2). Entryway soil lead concentrations were significantly correlated with boundary concentrations (.56, $p < .005$). The correlation between boundary and foundation lead concentrations was not significant. There were two indications of correlation between interior and exterior lead concentrations. Interior entryway dust lead concentrations were significantly correlated with entryway soil lead concentrations (.29, $p=.05$). Lead concentrations were also correlated for boundary soil and window stool dust (.38, $p=.01$).

There was significant correlation observed (Table 5-3) between dust loading on (interior) vacuum floors and exterior entryways (.33, $p = .03$). That is, houses with more dust outside the entryways tended to have more dust on the floors inside. There was also significant correlation between dust loadings in air ducts and dust loadings at the exterior entryways (.33, $p=.04$), and between window stools and window channels (.34, $p=.02$).

5.2 WITHIN-HOUSE CORRELATIONS

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Whereas the previous section discussed house-to-house variations in lead and dust levels, this section discusses within-house correlations among sample types. Thus, the purpose of this analysis is to determine if there is significant co-variation in lead levels as one moves from room to room or side to side at a house.

For interior dust samples (except floor samples), there was typically only one sample taken per room. For these sample types, it was impossible to estimate random room effects apart from within-room variation. Residuals from the fit of the full model were used in the correlation calculations. Therefore, for these sample types, the correlations presented in this section are really those of room-to-room plus within-room variation among the different dust sample types. For some pairs of sample types (e.g., entryway interior and floor vacuum), there were insufficient data to estimate the room-level correlations after fitting the full model. In these instances, the relevant entry in Tables 5-4, 5-5, and 5-6 is blank.

For floor and soil samples, side-by-side samples were taken at several locations. Therefore, the model included a room/side level random effect term for each location sampled. For these sample types, residuals from this model were averaged and added to the estimates of the room/side levels random effect to estimate within-house correlations.

To calculate degrees of freedom for estimating the within-house correlation of two sample types, A and B, the following method was used:

1. Let $h_{A,B}$ denote the number of houses from which samples of both types were taken, and

2. Let $l_{A,B}$ denote the number of locations from which both sample types were taken, and

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3. Let f_i^r denote the number of room-level fixed effects in the model fit for sample type (i=A,B).

4. $df_{A,B} = l_{A,B} - h_{A,B} - \max(f_A^r, f_B^r) - 2$.

Table 5-4 presents these correlations for lead loading; Table 5-5 presents the correlations for lead concentrations; and Table 5-6 presents the correlations for dust loading. The format used in these tables is the same as that of Tables 5-1, 5-2, and 5-3. Figure 5-4 displays scatterplot matrices of within-house level differences in lead loadings; Figures 5-5 and 5-6 provide the same for lead concentrations and dust loadings.

No significant correlations were found for lead loading. The only significant within-house level correlation in lead concentration was between interior and exterior entryway dust samples (.37, p=.03). Lead concentration for these two sample types were not at all correlated with lead concentrations in entryway soil samples, despite the fact that these estimates are based on many degrees of freedom. There were no significant correlations for dust loading.

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Table 5-4. Correlations* Among Sample Types for Within-House Random Effects: Lead Loading

	Air Duct	Window Channel	Window Stool	Floor (Wipe)	Floor (Vacuum)	Entryway Interior	Entryway Exterior (Dust)
Air Duct		.06 8 .86	.17 23 .42		.02 27 .90		
Window Channel			.27 21 .22		.12 20 .60		
Window Stool					.17 49 .24		.05 2 .95
Floor (Wipe)							
Floor (Vacuum)							
Entryway Interior							.14 31 .44
Entryway Exterior (Dust)							

* Top number is estimated correlation; middle number is degrees of freedom; and bottom number is significance level.

Table 5-5. Correlations* Among Sample Types for Within-House Random Effects: Lead Concentration

	Air Duct	Window Channel	Window Stool	Floor (Vacuum)	Entryway Interior	Entryway Exterior (Dust)	Entryway** (Soil)
Air Duct		.06 4 .90	.38 23 .06	.09 27 .64			
Window Channel			.34 21 .11	.14 20 .54			
Window Stool				-.01 49 .94		.05 2 .95	.17 3 .78
Floor (Vacuum)							
Entryway Interior						.37 31 .03	-.04 38 .81
Entryway Exterior (Dust)							-.14 41 .38
Entryway (Soil)							

* Top number is estimated correlation; middle number is degrees of freedom; and bottom number is significance level.

** Foundation and boundary soil samples are not represented in this table because there is not a clear link between interior dust samples (e.g., the window stool of an interior room) and soil samples near the boundary or near the foundation, except at the entry. Even though a link can be made if the boundary or foundation soil sample was collected on the same side of the house as an entry, there were too few cases to warrant this.

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Table 5-6. Correlations* Among Sample Types for Within-House Random Effects: Dust Loading

	Air Duct	Window Channel	Window Stool	Floor (Vacuum)	Entryway Interior	Entryway Exterior (Dust)
Air Duct		-.20 8 .57	-.11 23 .64	.11 27 .55		
Window Channel			.15 21 .48	-.02 20 .93		
Window Stool				.26 49 .07		.156 2 .84
Floor (Vacuum)						
Entryway Interior						.04 31 .85
Entryway Exterior (Dust)						

* Top number is estimated correlation; middle number is degrees of freedom; and bottom number is significance level.

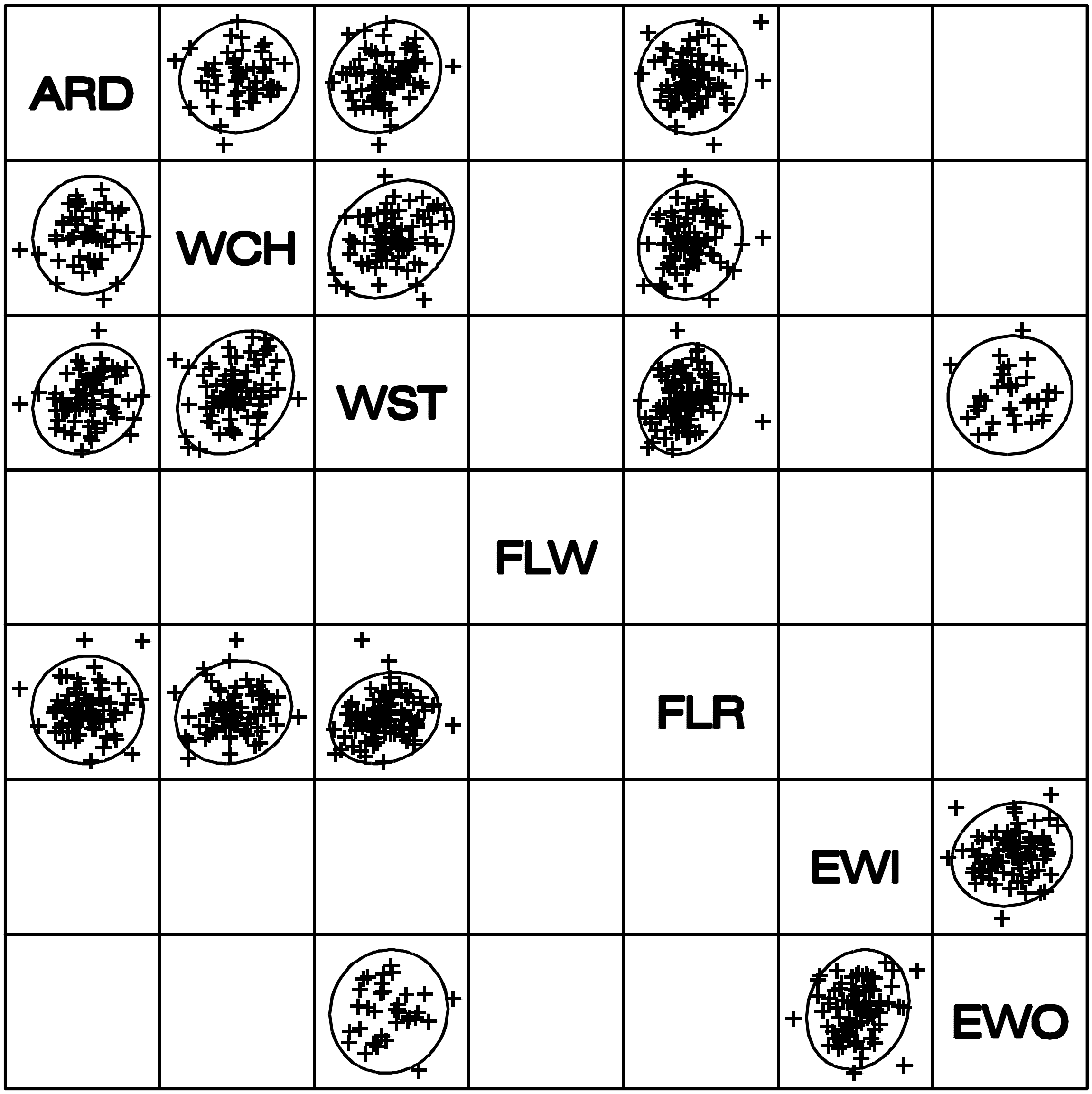


Figure 5-4. Scatterplot matrix of room-level random effects for different sample types: lead loading (µg/ft²).

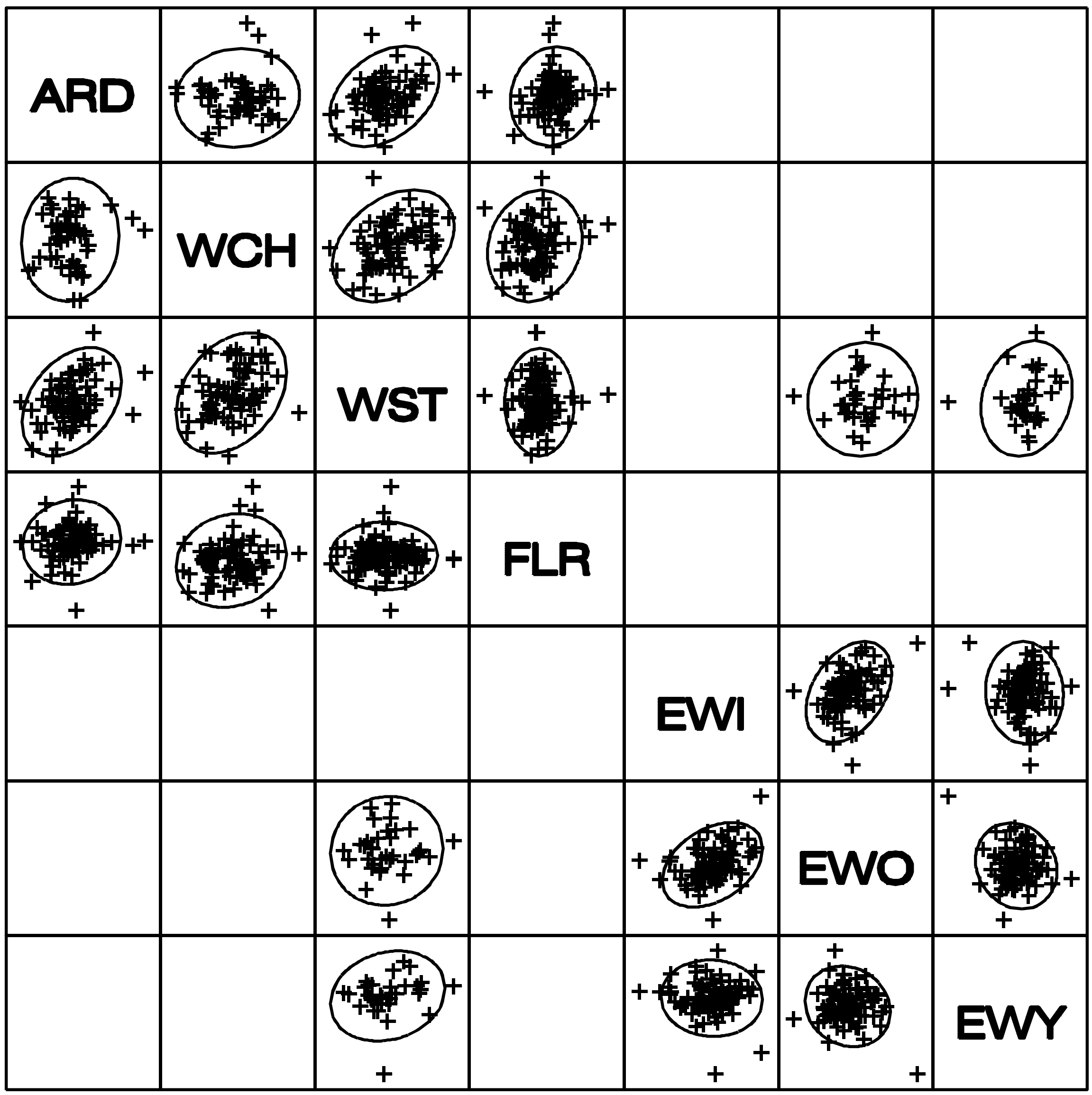


Figure 5-5. Scatterplot matrix of room-level random effects for different sample types: lead concentration (µg/g).

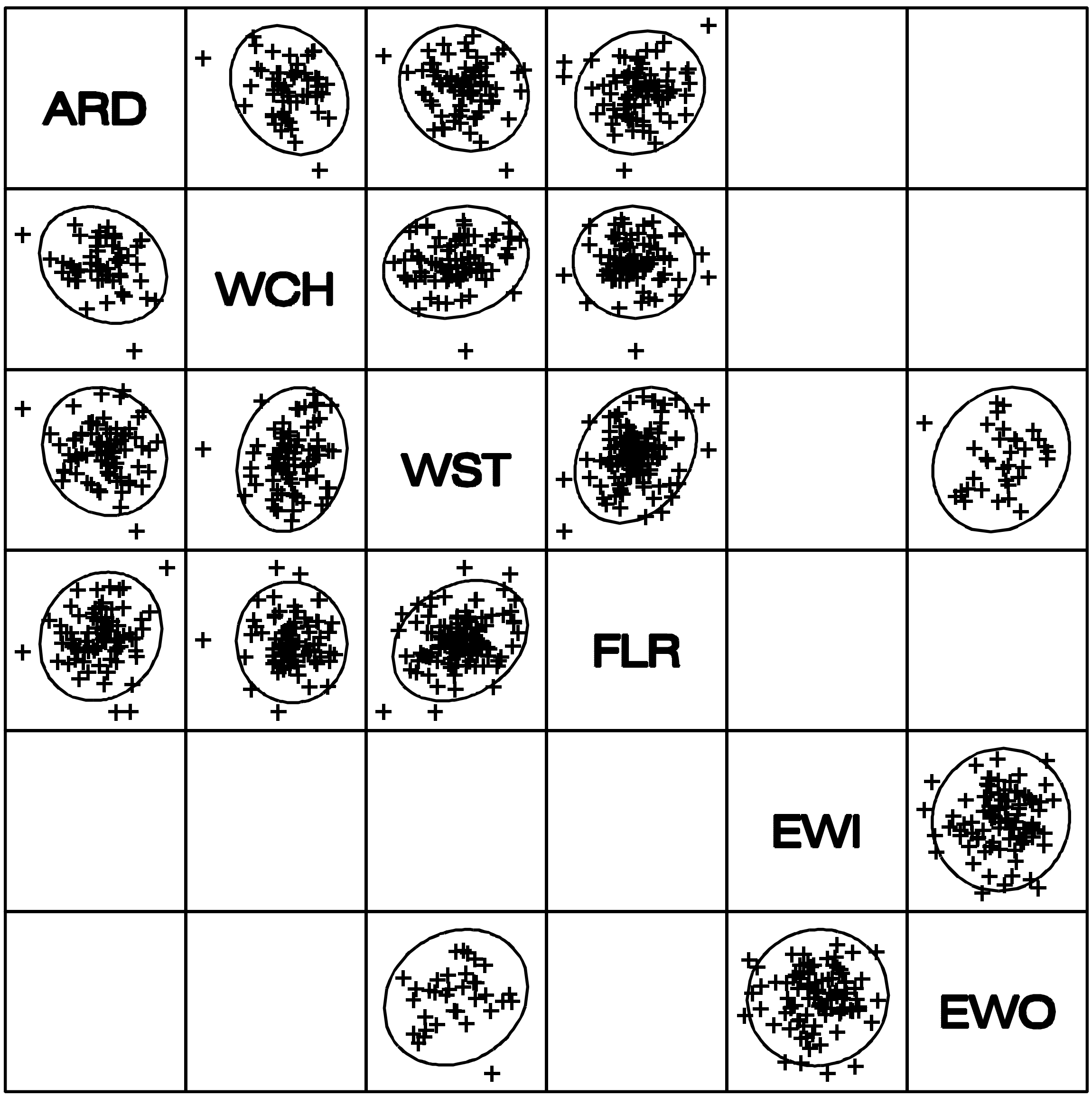


Figure 5-6. Scatterplot matrix of room-level random effects for different sample types: dust loading (µg/g).

6.0 WIPE VERSUS VACUUM COMPARISON

The two major HUD programs investigating levels of lead in household dust utilized different sampling methods. In the Demonstration Study, dust was wipe sampled. In the National Survey, dust was vacuum sampled. As part of the CAP Study, several side-by-side dust samples were taken by the wipe and vacuum sampling methods. This chapter presents a comparison of both the wipe and vacuum sampling methods. The methods are compared across all substrates and by substrate.

To investigate the relationship between lead loading determinations made by the two methods, four side-by-side samples were taken from a selected room in each abated house. Two of the samples were taken by the vacuum method and two by the wipe method. Samples were collected in 34 of the 35 abated houses sampled. In one house (House 61), all floors were carpeted so no wipe/vacuum comparison samples were taken. In another house (House 50), the substrate for one of the vacuum samples was half linoleum and half concrete, so this house was included in the comparison of methods pooled across substrates, but excluded from the analysis by substrate. Of the remaining 33 abated houses, one of the comparison samples in house 21 was lost during analysis. This also happened to be the only house in which both the wipe and the vacuum comparison samples were taken from a concrete floor. The three observed loadings were substantially higher than corresponding measures in all the other houses. The analysis was performed both with and without the data from this house. The results were only slightly different when this house is excluded, but due to the imbalance it was excluded from the calculation of the results provided below.

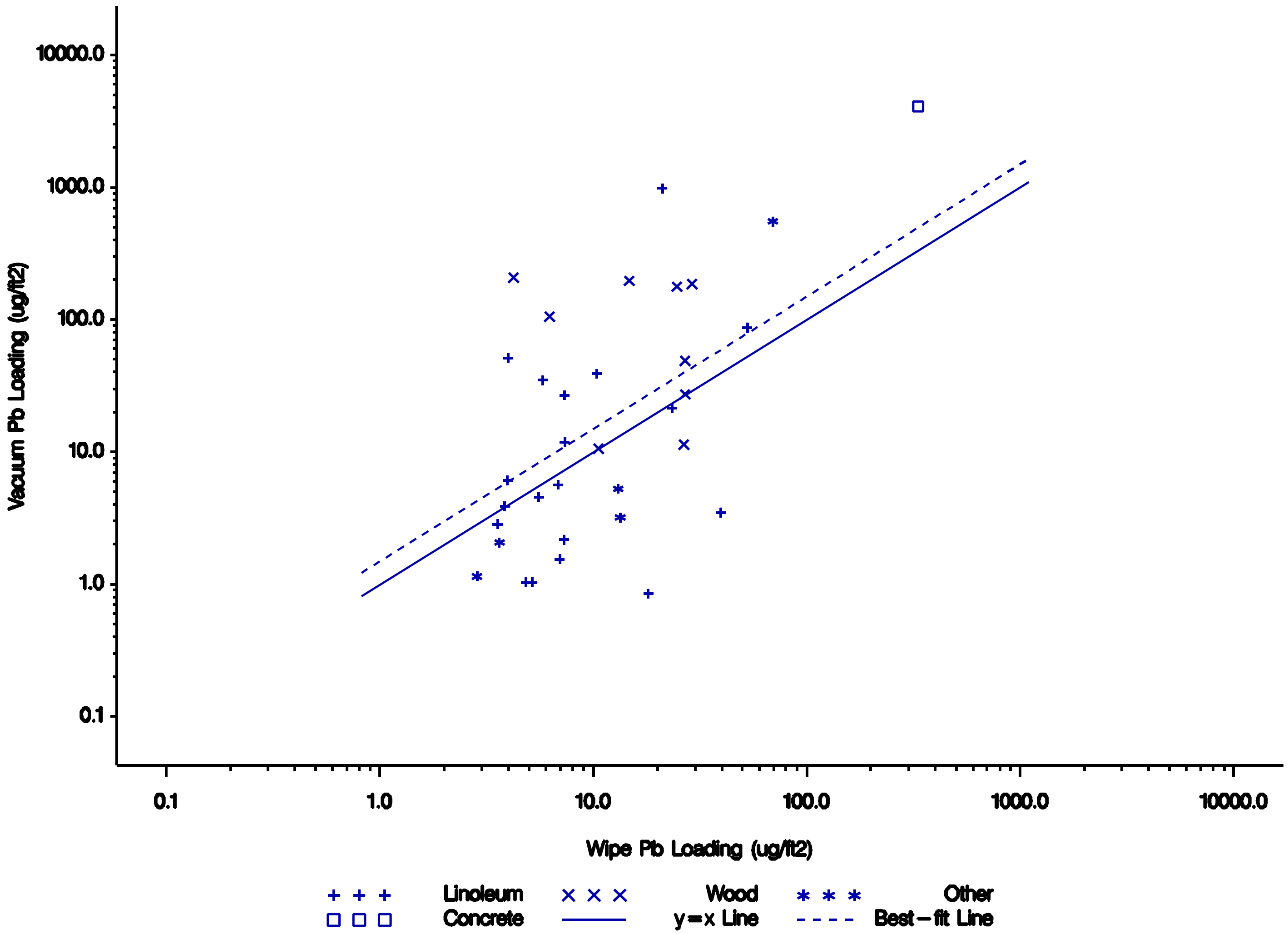
The geometric means of the paired floor lead loadings are listed in Table 6-1 and plotted in Figure 6-1. In the figure, lead loadings from vacuum samples are plotted versus lead loadings from wipe samples. A solid reference line which represents complete agreement between the two sampling methods is

Table 6-1. Vacuum versus Wipe Comparison Data: Room Geometric Mean Floor Lead Loadings (ug/ft^2)

Substrate	Unit	Location	Vacuum Loading	Wipe Loading
Concrete	21	LDY	4075.33	333.56
Linoleum	93	KIT	6.07	3.96
	44	HAL	3.89	3.84
	25	KIT	2.84	3.56
	96	BAT	38.93	10.41
	46	BAT	0.85	18.07
	77	KIT	5.63	6.85
	7	KIT	26.77	7.34
	18	KIT	34.81	5.82
	69	KIT	51.23	4.00
	70	KIT	1.03	5.18
	80	KIT	980.96	21.10
	10	KIT	11.83	7.37
	40	BAT	1.03	4.83
	50*	BSM	4.57	5.57
	71	KIT	21.35	23.31
	81	KIT	3.47	39.70
	31	HAL	87.02	52.69
	41	KIT	2.17	7.30
	72	KIT	1.55	6.94
Tile	47	BA2	1.14	2.86
	9	KIT	3.19	13.37
	90	KIT	552.54	69.37
	60	KIT	2.06	3.64
	51	KIT	5.24	13.05
Wood	74	BD2	48.26	45.11
	84	KIT	195.17	14.76
	94	KIT	27.06	26.92
	24	LDY	206.14	4.24
	55	LVG	10.53	10.56
	17	LVG	104.66	6.26
	99	DIN	175.91	24.71

	39	KIT	11.24	26.61
	11	DIN	183.66	28.97

* The substrate for one of the vacuum samples collected at this house was half linoleum and half concrete. Therefore, this house was excluded in the estimation of multiplicative biases by substrate.



10000.0
1000.0
100.0
10.0
1.0
0.1
Vacuum Pb Loading (ug/ft2)
0.1
1.0
10.0
100.0
1000.0
10000.0
Wipe Pb Loading (ug/ft2)
Linoleum
Wood
Other
Concrete
y=x Line
Best-fit Line

Figure 6-1. Vacuum versus wipe comparison: geometric means of side-by-side floor lead loading (µg/ft²) measures. (Estimate of vacuum/wipe ratio is 1.38; confidence interval is (0.75, 2.54).)

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also plotted along with the best fit regression line. A statistical analysis was performed to quantify this relationship. This is discussed in Section 6.1. Samples taken on different substrates (linoleum, wood, concrete, or tile) are distinguished by different plotting symbols in Figure 6-1. Since the relationships between vacuum and wipe responses were different for each substrate, the analysis was also performed adjusting for substrate. This analysis is discussed in Section 6.2.

The effect of room type on the wipe/vacuum relationship was also investigated. Categories such as wet versus dry and eating versus non-eating were considered. No significant differences were observed.

6.1 ALL SUBSTRATES COMBINED

It was assumed that the relationship between vacuum and wipe measures is log-linear:

$$\log(V) = \log('') + \$ \log(W) \qquad (1)$$

where V and W represent the true expected loadings by the vacuum and wipe methods. Restating the model in terms of the untransformed loadings gives

$$V = '' \, W^{\$}. \qquad (2)$$

If $ is not equal to one, the multiplicative bias between the two sampling methods changes with the magnitude of the measurements. However, if $=1, there is a fixed multiplicative bias (") between the sampling methods which does not change with the magnitude of the measurements. Also, for $=1, the model of Equations (1) and (2) simplifies to the assumption that the ratio W/V follows a lognormal distribution with geometric mean ".

Since the vacuum and wipe determinations are both measured with error, a simple linear regression for (1) is inappropriate. An errors-in-variables approach was used. Specifically, V and W in (1) are not observed, but rather V* and W* where

$$\log(V^*) = \log(V) + \log(,), \text{ and}$$
$$\log(W^*) = \log(W) + \log(*),$$

with , and * independent and lognormally distributed. Using simple linear regression produces biased estimates of " and $. However, formulas to correct for these biases are known (See Draper and Smith, 1981, p. 123), and were used in the results that follow.

All of the data described in Table 6-1 was used in this analysis except for those samples collected on concrete (House 21). Thus 33 pairs were used. The first step was to test the hypothesis of a fixed multiplicative bias (H_o:$=1). The estimate of $ was 1.32 with a standard error of 0.43. Since the hypothesis could not be rejected at any reasonable significance level (p=0.46), the model was then refitted with the $ parameter set to one. The estimate of the multiplicative bias (") of vacuum over wipe measurements is 1.38 with a 95% confidence interval of (0.75, 2.54). This result implies that, on the average, vacuum lead loadings are 1.38 times larger than matching wipe lead loadings on floors.

The precision of the vacuum and wipe measurements is also a relevant quantity. On average, side-by-side vacuum measures were significantly more variable than wipe measures. The estimated log standard deviation for vacuum samples was 0.96 with a 95 percent confidence interval of (0.77, 1.26) whereas for wipe samples it was 0.55 with a 95 percent confidence interval of (0.45, 0.73).

6.2 ADJUSTING FOR SUBSTRATE EFFECTS

The above approach was used to investigate the vacuum/wipe relationship separately for each of the substrate categories sampled. For each of the substrates, the hypothesis of a fixed multiplicative bias ($=1) could not be rejected at any reasonable level. For each substrate separately, multiplicative bias estimates were derived assuming $=1. There was only one set of side-by-side comparison samples taken on concrete, so no estimates are provided for this substrate. Also, in one house (House 50) it was not possible to collect four side-by-side samples from entirely the same substrate. Three of the samples were collected on linoleum but half of one of the vacuum samples was collected from concrete. Therefore this sample was deleted from the analysis for linoleum samples.

The estimated biases vary according to substrate. There appears to be a relationship between the smoothness of the substrate and these biases. Table 6-2 displays the estimated multiplicative bias for each substrate along with confidence bounds. The ratio observed on wood was different from the ratios observed on both linoleum and tile, although the confidence intervals overlap. The bias appears to increase with coarseness of the substrate. If the wipe method fails to extract dust particles embedded in recesses on the substrate surface then this relationship would be expected.

Table 6-2. Vacuum/Wipe Multiplicative Bias Estimates

Substrate	Sets of Observations	Estimated Vacuum/Wipe Multiplicative Bias	Lower Confidence Bound	Upper Confidence Bound
Tile	5	0.69	0.12	3.90
Linoleum	18	1.02	0.42	2.44
Wood	9	3.92	1.13	13.59

7.0 COMPARISONS WITH OTHER STUDIES

The environmental sampling results of the CAP Study may be compared to those from other studies. In particular, comparisons to the earlier CAP Pilot Study, the HUD Abatement Demonstration Project, and other studies assessing the efficacy of an abatement procedure seem most applicable. Section 7.1 compares the results from the pilot and full CAP studies. A comparison to the HUD Demonstration results is presented in Section 7.2; and the CAP results are compared to the results of other abatement efficacy studies in Section 7.3.

7.1 COMPARISON OF CAP STUDY DATA AND CAP PILOT STUDY DATA

The CAP Pilot Study investigated field, laboratory, and statistical analysis procedures planned for the CAP Study. The CAP Pilot Study samples were collected in May 1991, as compared to the CAP Study sampling in March and April 1992. A complete discussion on the Pilot Study is available in another report (EPA, 1995a).

Of the six residential houses surveyed in the Pilot Study, five were revisited in the CAP Study. Figure 7-1 displays the differences for those five houses between the CAP Pilot and full CAP study geometric mean lead loading results, by sample type. Similar plots for lead concentration and dust loading are presented in Figures 7-2 and 7-3, respectively. Each line segment in the figures represents the change in lead loading for a particular house and sample type. For example, the vacuum floor lead loading results were higher in the full study than in the Pilot for all houses except House 51. In the figure, this is evidenced by the appropriate line segments rising from left to right.

As the figures suggest, when comparing the CAP Pilot and the CAP Study results, there is no single pattern of change across the various sample types. For example, a particular house may have higher air duct lead loadings in the CAP Study than in the

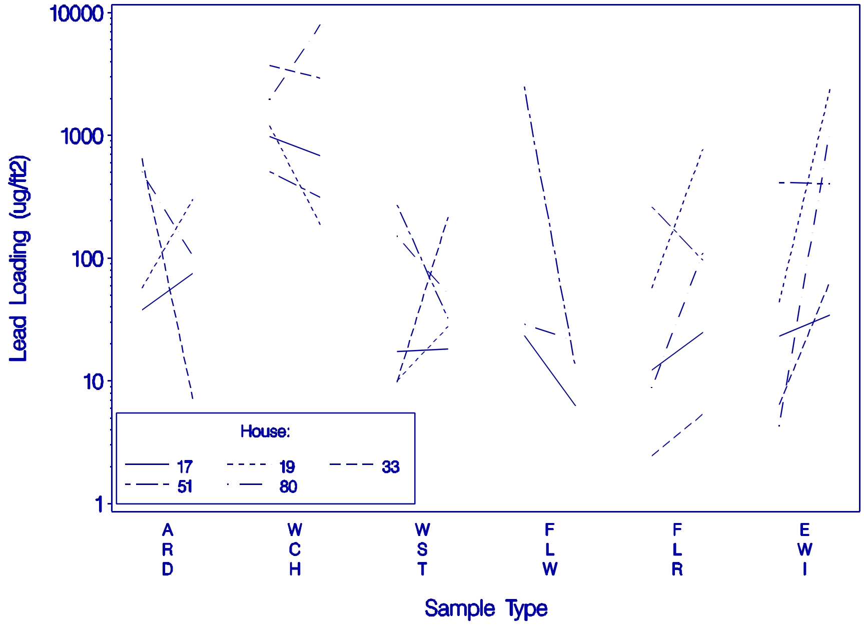

Figure 7-1. Comparison of CAP Pilot Study and CAP Study results: unit geometric mean lead loading (µg/ft²) by sample type.

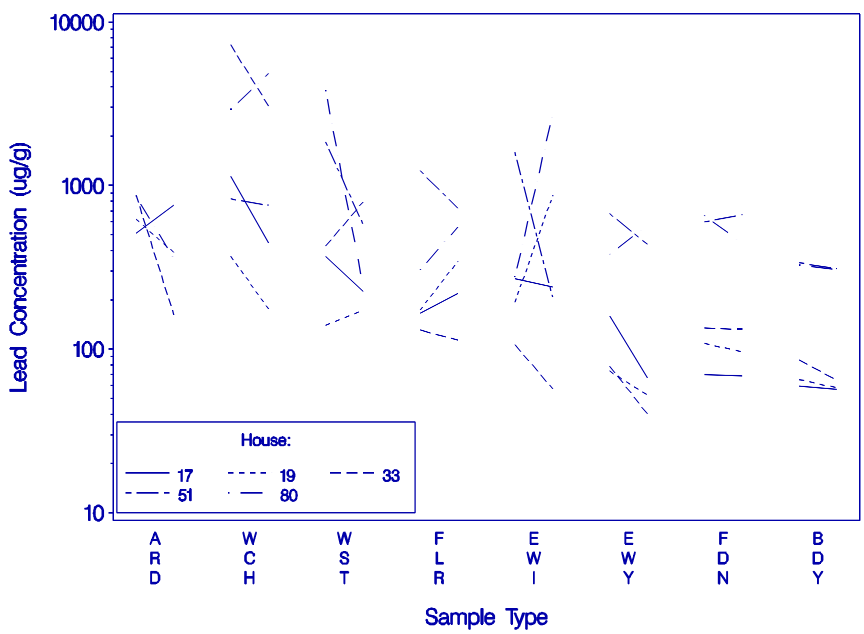

Figure 7-2. Comparison of CAP Pilot Study and CAP Study results: unit geometric mean lead concentration (µg/g) by sample type.

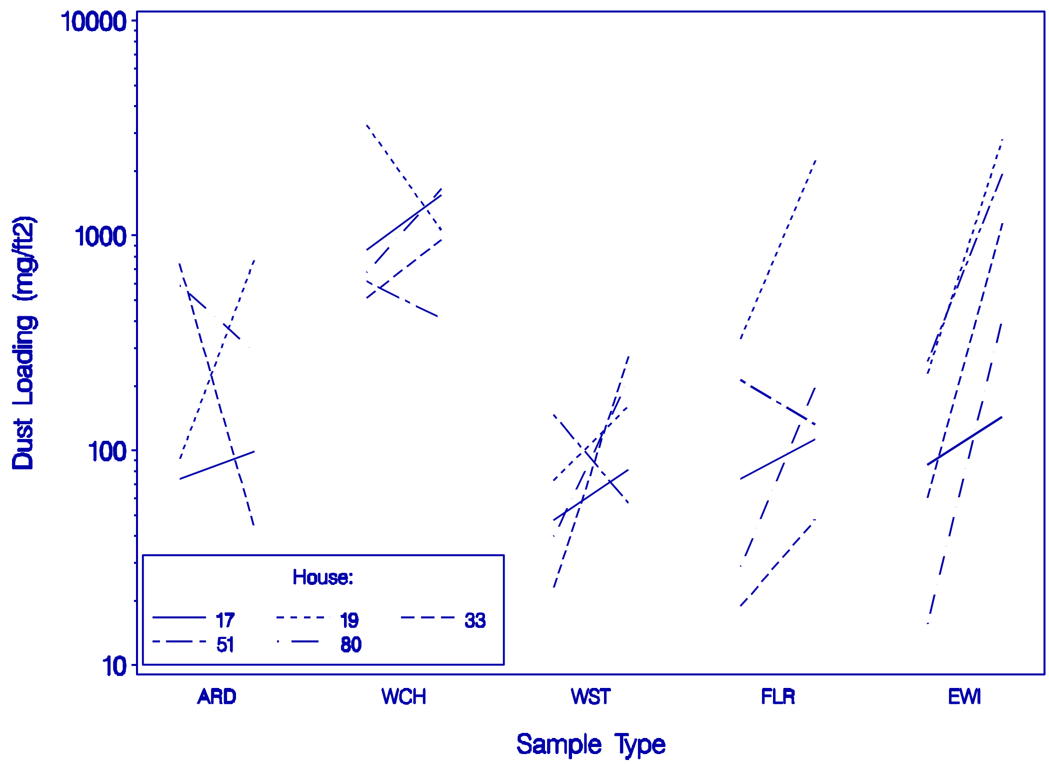

Figure 7-3. Comparison of CAP Pilot Study and CAP Study results: unit geometric mean dust loading (mg/ft^2) by sample type.

Pilot, but lower window channel lead loadings. The vacuum floor and interior entryway changes are the most similar house to house, especially for the lead loading and dust loading results. The window channel and window stool results, in turn, were the least consistent. Not surprisingly, the soil lead concentration measurements did not change significantly in the time between the two studies. Also, despite the greater efficiency of the dust sampler used in the full CAP Study, the dust loading house geometric means did not all increase. In fact, the dust loading results for House 51 were usually lower in the CAP Study than the Pilot Study. Across the various sample types, only the air ducts had an average decrease in dust loadings. The greatest geometric mean increase in dust loading, 9.5 times, occurred for vacuum floor samples. Since the CAP Study only collected wipe samples from abated houses, only three houses had wipe sampling results from both the Pilot and full studies. The lead loading results in those houses were lower in the full CAP Study.

It was noted above that a more efficient dust vacuum sampler was utilized in the CAP Study. When revisiting the Pilot houses in the CAP Study, an attempt was made to collect dust samples from the same room and component. Figure 7-4 presents a comparison of the dust loading results from these two studies. The dust loading results for the Pilot Study are plotted versus those for the CAP Study. The different sample types are indicated by individual plotting symbols. The cloud of points and their location are somewhat surprising. Given the greater efficiency of the sampler used in the CAP Study, one might have expected the CAP Study dust loadings to be consistently higher than the Pilot Study results. Evidently, other factors such as

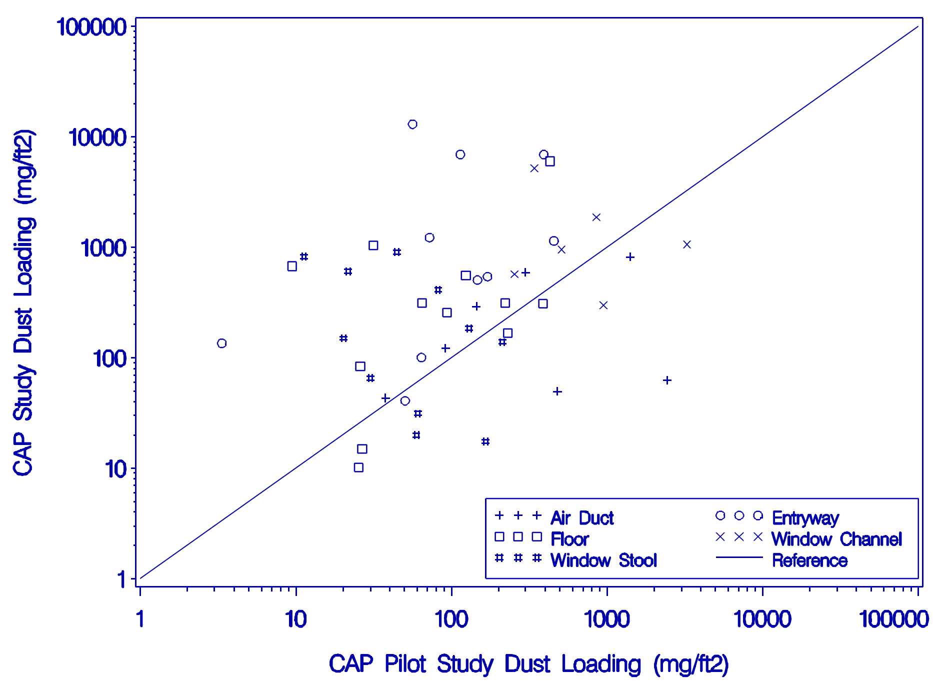

Figure 7-4. Comparison of CAP Pilot Study and CAP Study results: component geometric mean dust loadings (mg/ft^2) by sample type.

time, occupancy, and sample-to-sample variation are just as important as sampling efficiency for determining the dust loading.

7.2 COMPARISON OF CAP STUDY DATA AND HUD ABATEMENT DEMONSTRATION DATA

The HUD Abatement Demonstration project included an assessment of the extent to which lead-based paint was present in approximately 300 residential housing units. Houses selected for abatement of lead-based paint had dust samples collected from individual components within a room primarily after abatement, and soil core samples collected on all four sides of the house (both before and after the abatement). The HUD Demonstration pre-abatement samples were collected between August and December 1989. The post-abatement samples were collected between November 1989 and July 1990. The CAP Study results, in turn, were obtained in March and April 1992. Though a seasonal effect may be influencing the comparisons that follow, it cannot be separated from other differences between the projects such as sampling protocols.

Figure 7-5 illustrates the observed CAP Study lead loadings versus HUD Demonstration pre-abatement lead loadings for floor, window channel, and window stool samples. Different symbols are used for each sample type, including wipe and vacuum floor samples. Figure 7-6 illustrates the corresponding results for foundation soil lead concentrations.

Table 7-1 displays the results of a comparison of pre- and post-abatement measures collected during the HUD Demonstration. Results are restricted to floor, window channel, and window stool dust lead loadings and foundation soil lead concentrations. The top half of the table portrays statistics concerning the ratio of CAP results to pre-abatement HUD Demonstration measures; the bottom half of the table compares HUD Demonstration short-term post-abatement measures with the CAP results.

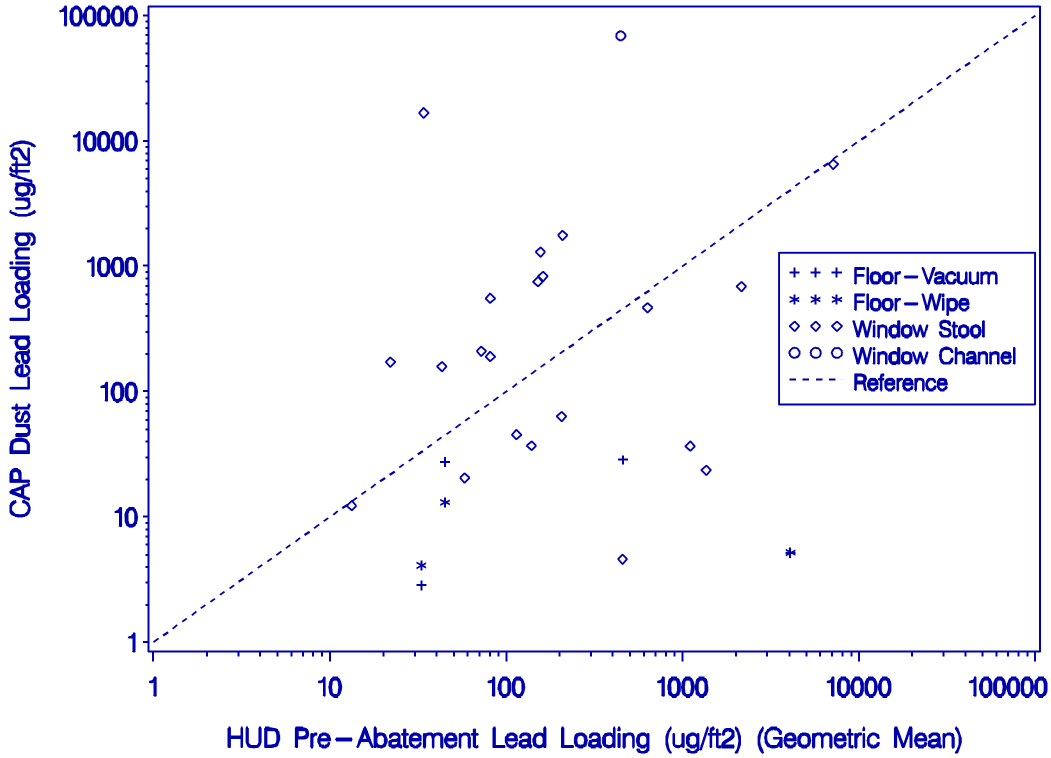

Figure 7-5. CAP versus HUD Demonstration pre-abatement lead loadings: floor, window channel, and window stool dust.

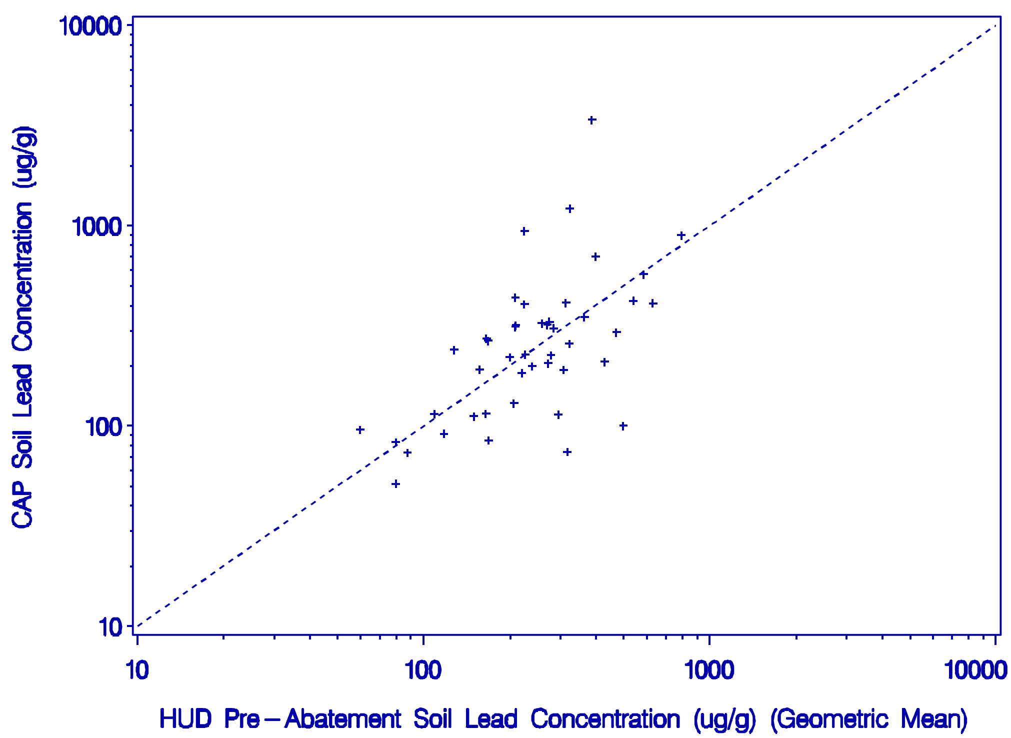

Figure 7-6. CAP versus HUD Demonstration pre-abatement lead concentration: foundation soil.

Table 7-1. Comparison of CAP Lead Levels with HUD Demonstration Pre- and Post-Abatement Lead Levels

Ratio of CAP Lead Levels to Pre-Abatement HUD Demonstration Lead Levels					
Sample Type	N	Geometric Mean	Lower Bound	Upper Bound	Signifi-cance
Floor Dust Lead Loading	7	0.04	0.004	0.41	.01
Window Stool Dust Lead Loading	21	1.14	0.37	3.46	.81
Foundation Soil Lead Concentration	45	1.02	0.83	1.24	.88
Ratio of CAP Lead Levels to Post-Abatement HUD Demonstration Lead Levels					
Sample Type	N	Geometric Mean	Lower Bound	Upper Bound	Signifi-cance
Floor Dust Lead Loading	147	1.21	0.87	1.68	.26
Window Channel Dust Lead Loading	38	40.4	19.5	83.9	<.01
Window Stool Dust Lead Loading	67	2.77	1.45	5.28	<.01
Foundation Soil Lead Concentration	68	0.88	0.75	1.03	.12

This table demonstrates that there were relatively few pre-abatement samples available for comparison. Only one pair of window channel samples was comparable, and therefore window channel results were not compared in this table. In addition, there were only seven floor samples collected in the CAP Study for which a corresponding pre-abatement lead level was available. Of these seven CAP study floor samples, four were collected by wipe and three were collected by vacuum. Thus, only the results for window stools and foundations should be used to form conclusions about the direct effect of abatement.

The ratios for window stool lead loading were more variable than the ratios for foundation lead concentration, but neither mean ratio was significantly different from one. The geometric mean ratio of lead loadings observed in the CAP Study to corresponding pre-abatement levels on window stools was 1.14, with a 95 percent confidence interval of 0.37 to 3.46. This is based on 21 samples from 10 houses.

For foundation soil, the geometric mean ratio of lead concentration in the CAP Study to pre-abatement levels was 1.02, based on 45 samples from 24 houses. This has a 95 percent confidence interval of 0.83 to 1.24. Both of these results imply that pre-abatement and CAP results were not significantly different.

More data was available to assess ratios of CAP lead loadings to HUD post-abatement lead loadings. These ratios were generally higher than those for pre-abatement lead loadings. Specifically, the geometric mean ratio of lead loading in the CAP Study to HUD post-abatement levels was 40.4 for window channels. For window stools, the ratio was 2.77.

Figure 7-7 contrasts the CAP Study floor dust lead loading ($\mu g/ft^2$) results to post-abatement results from the HUD Demonstration. For the CAP Study, geometric mean dust lead loadings are calculated for all floor dust vacuum and wipe samples collected within a room and house. Since the post-abatement dust samples collected in the HUD Demonstration project were part of the clearance procedure, only the final floor dust wipe sample collected in a room was retained. Figures 7-8 and 7-9 present similar comparisons for window stools and window channels, respectively. Recall that in the CAP Study, dust wipe samples were collected only on the floors of abated houses. As is evidenced in the figures, there is little agreement between the CAP Study results and those from the HUD Demonstration. The higher dust lead loadings from the CAP Study, most apparent for the window channel samples, may be due to increased lead concentration in the dust, the greater efficiency of the vacuum

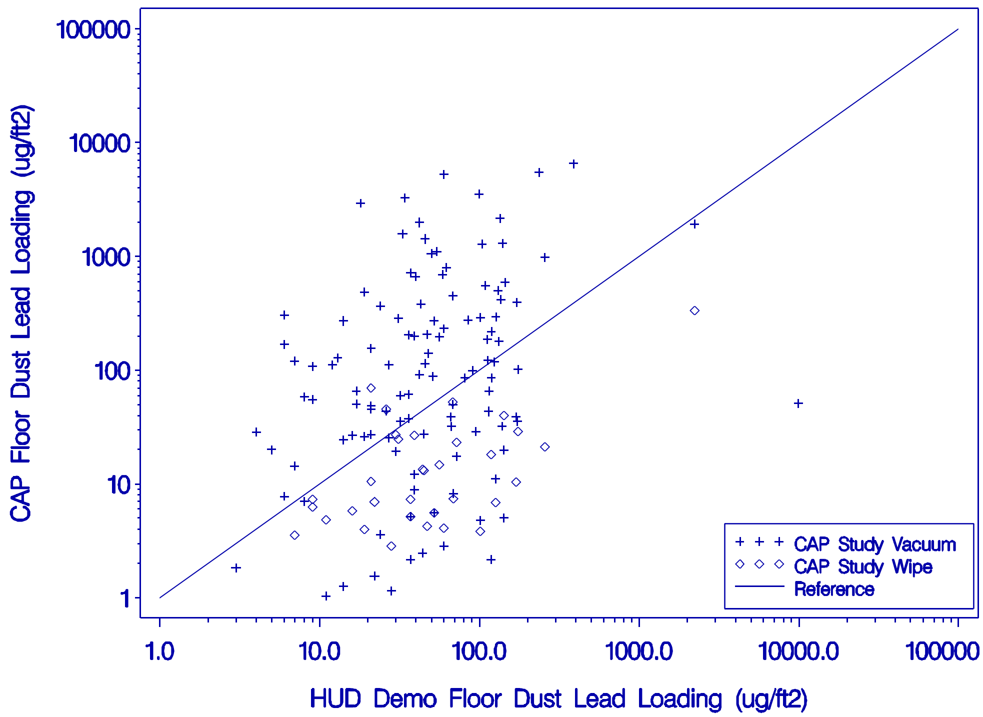

Figure 7-7. CAP vacuum and CAP wipe vs HUD Demonstration wipe results: geometric mean floor lead loading by room.

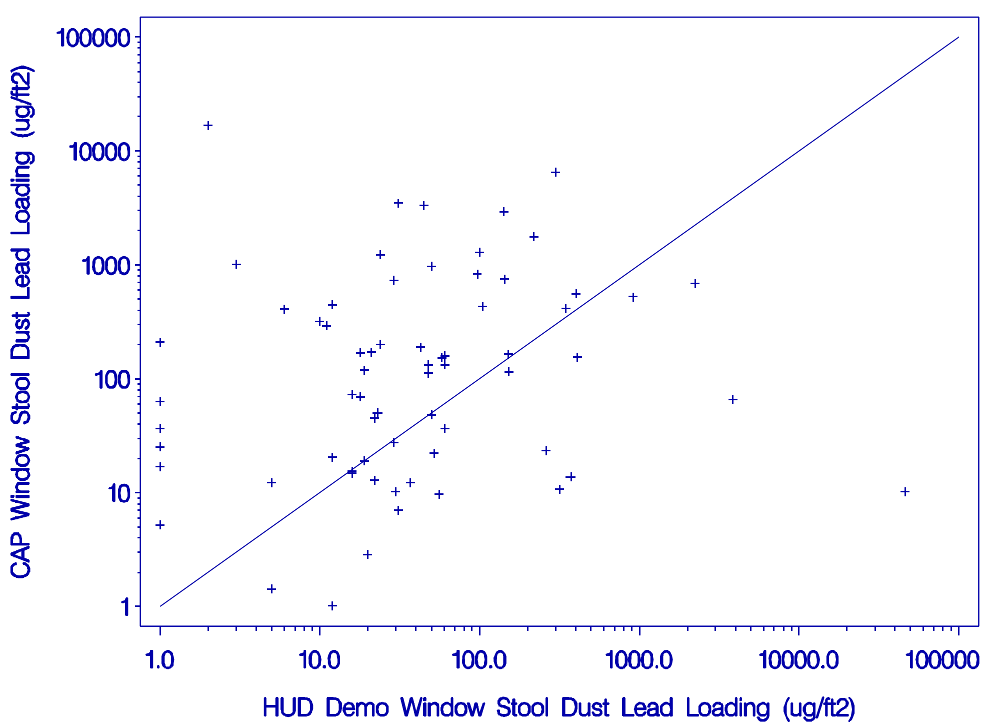

Figure 7-8. CAP vacuum versus HUD Demonstration wipe results: geometric mean window stool lead loadings by room.

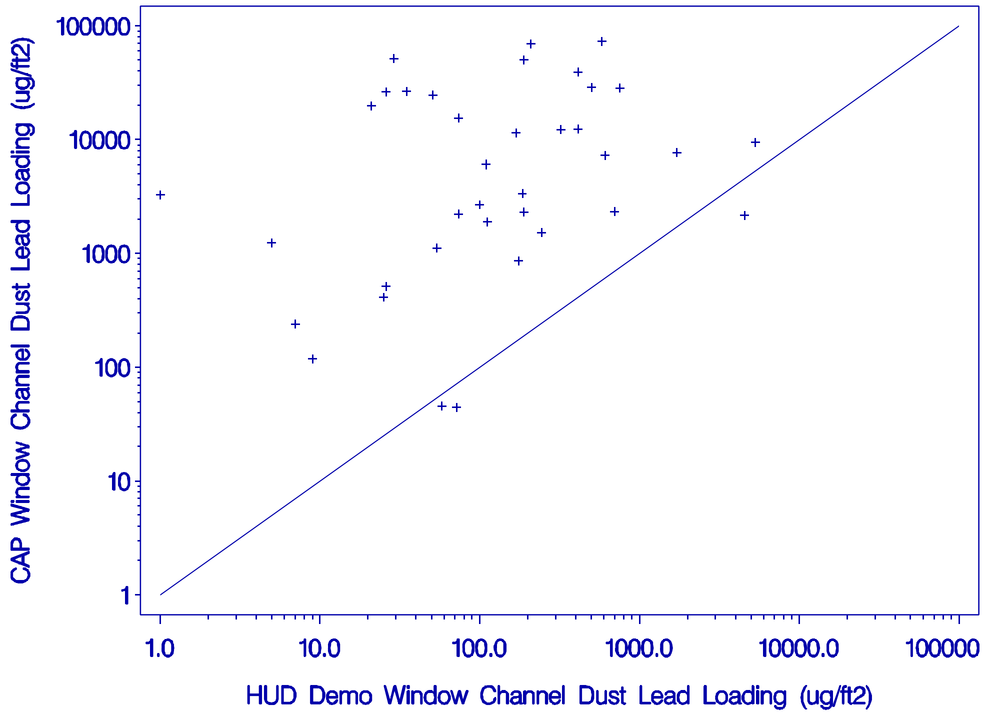

Figure 7-9. CAP vacuum versus HUD Demonstration wipe results: geometric mean window channel lead loading by room.

For purposes of comparison, a geometric mean XRF/AAS result (mg/cm^2) was calculated by room and house from the extensive HUD Demonstration XRF/AAS measurements within the room. Figure 7-10 compares the CAP Study floor dust lead loading results (both wipe and vacuum) and the HUD Demonstration dust wipe lead loadings to these room geometric mean XRF/AAS results. Similar comparisons are portrayed for window stools (Figure 7-11) and window channels (Figure 7-12). The resulting clouds of points suggest little or no correlation between dust lead loading and the XRF/AAS results for both the HUD Demonstration and the CAP Study projects. The scatter is somewhat more pronounced at lower XRF paint-lead loadings. Higher dust lead loadings are at times evident for the CAP dust vacuum samples and again particularly so for the window channel results.

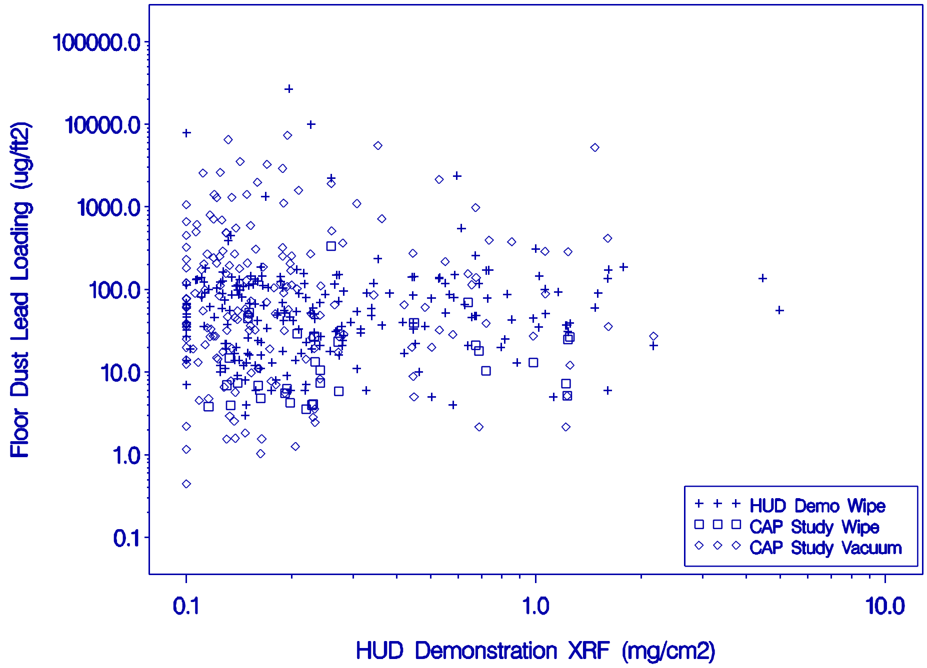

Figure 7-10. CAP wipe, vacuum, and HUD Demonstration wipe versus HUD Demonstration XRF/AAS results: geometric mean floor lead loading (µg/ft²) by room.

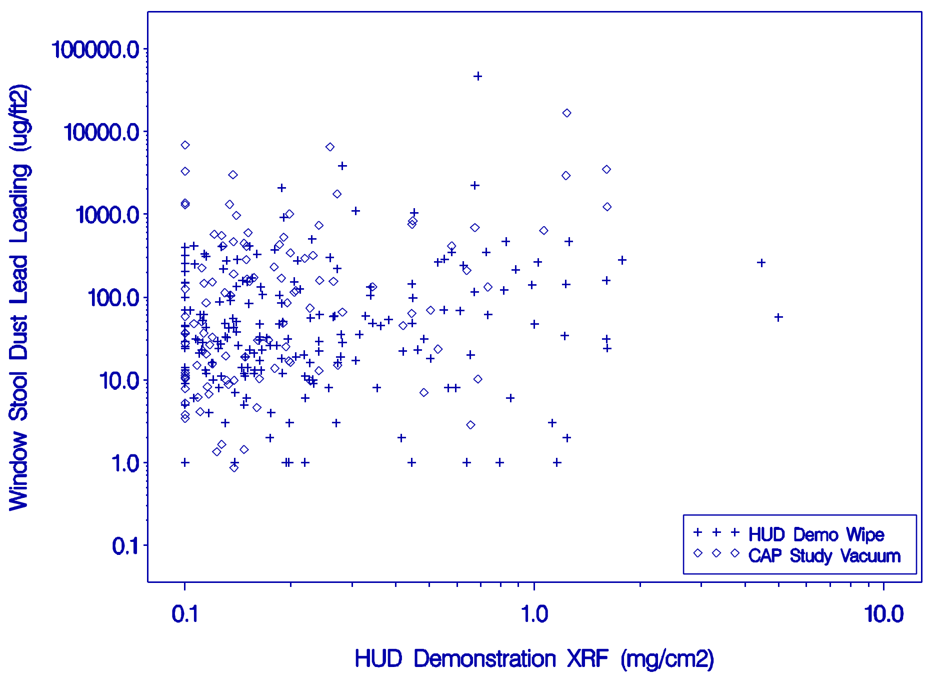

Figure 7-11. CAP vacuum and HUD Demonstration wipe versus HUD Demonstration XRF/AAS results: geometric mean window stool lead loading (µg/ft²) by room.

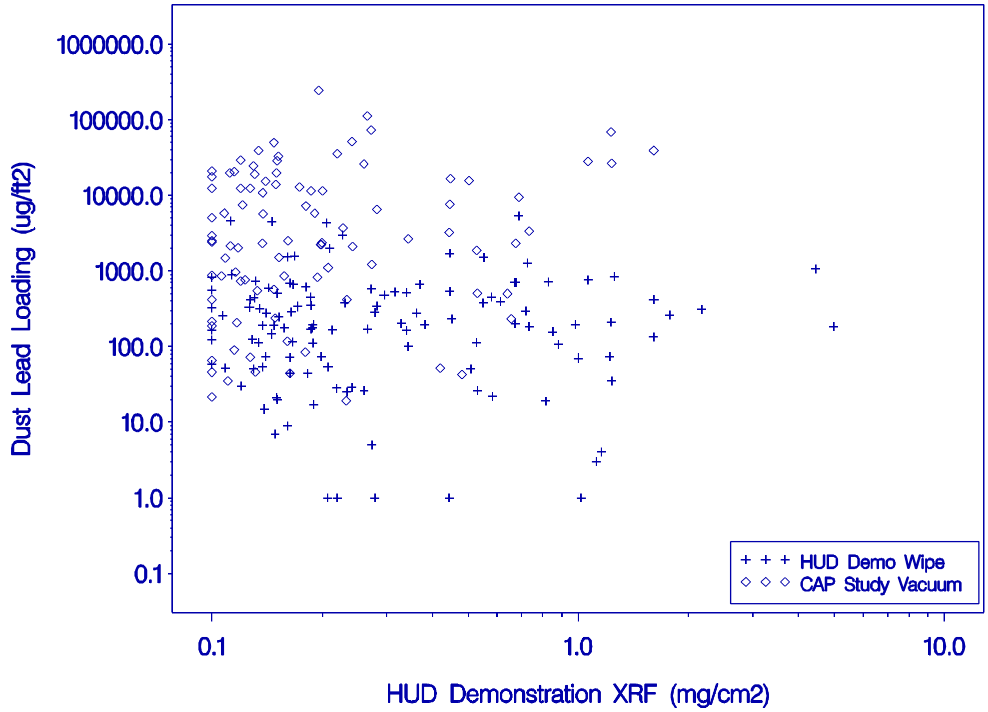

Figure 7-12. CAP vacuum and HUD Demonstration wipe versus HUD Demonstration XRF/AAS results: geometric mean window channel lead loading (µg/ft^2) by room.

Figure 7-13 compares the HUD Demonstration and CAP studies relative to soil lead concentrations (µg/g), collected at the foundation on the same side of the house. The pre-abatement soil samples are also included as a basis of comparison. The HUD Demonstration pre- and post-abatement results appear positively correlated. The CAP soil lead concentrations, in contrast, exhibit a higher degree of scatter than the pre-abatement results.

In Figure 7-14, soil lead concentrations (µg/g) are plotted versus the HUD Demonstration XRF/AAS paint-lead loadings (mg/cm^2), measured for the adjacent exterior wall. As was noted earlier in Section 4.2.2.2 (Figure 4-8), there was a significant association between the CAP soil lead concentrations and the HUD Demonstration XRF/AAS results when abated and unabated houses were considered separately. The HUD Demonstration pre-abatement soil results did not appear to exhibit any trend with increasing paint-lead loading, however. The HUD post-abatement soil results were positively correlated with paint-lead loading (.29, p=.03).

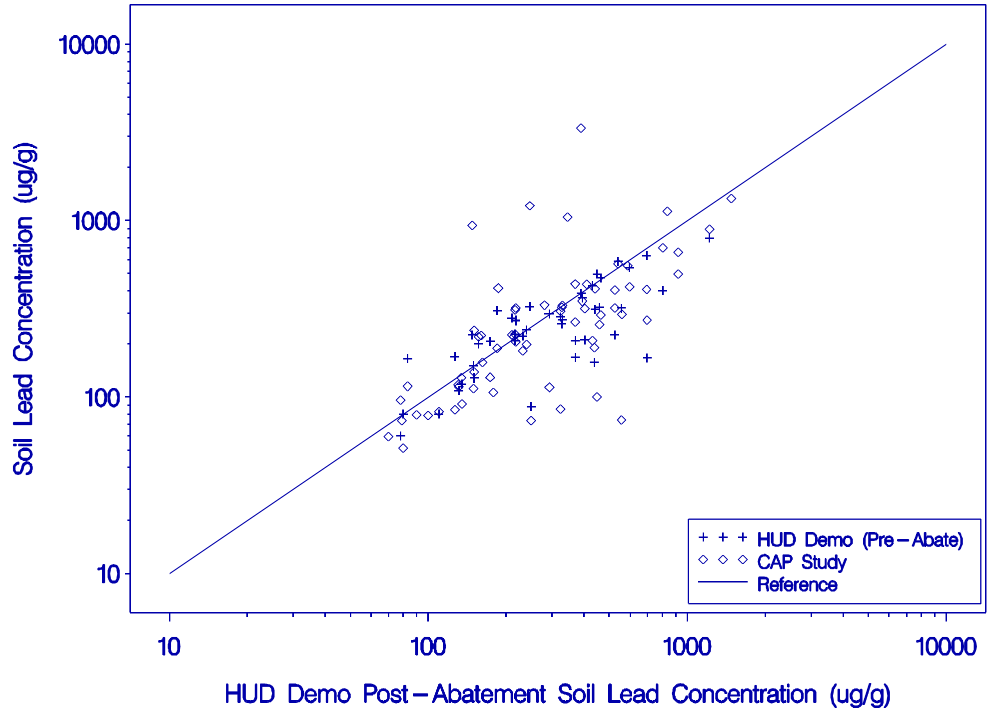

Figure 7-13. CAP versus HUD Demonstration results: geometric mean foundation soil lead concentration (μg/g) by side of unit.

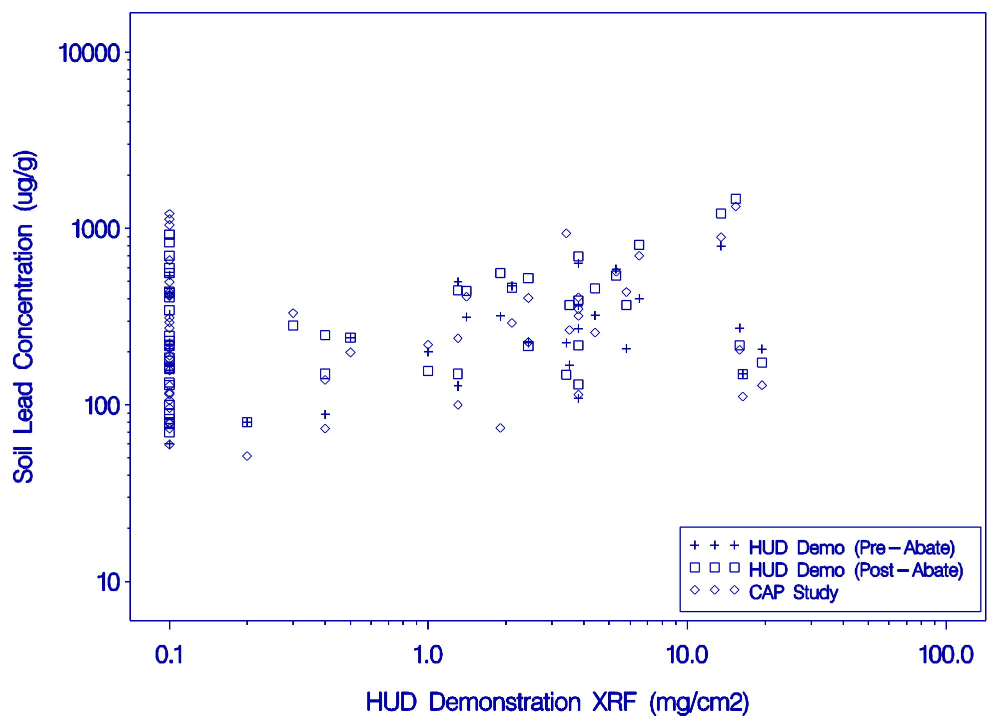

Figure 7-14. CAP soil concentration (μg/g) and HUD Demonstration soil concentration (μg/g) versus HUD Demonstration XRF/AAS results: geometric mean by side of unit.

7.3 COMPARISON OF DUST LEAD LOADINGS BETWEEN THE CAP STUDY AND OTHER STUDIES

It is useful to contrast the CAP Study dust lead loading results with those from other comparable studies, including the HUD Demonstration Study. Though considerable differences exist in the sampling frames, collection procedures, and instrumental analyses used in each study, the respective lead loading results may still provide insight on the range of environmental lead levels which exist in U.S. housing. The following four field studies were examined:

- HUD Abatement Demonstration Study,
- HUD National Survey of Lead-Based Paint,
- Kennedy-Krieger Traditional versus Modified Practices Study, and
- Kennedy-Krieger Experimental Abatement Practices Pilot Study.

The dust lead loading results for these studies were either calculated from available datasets or extracted from reported results in the scientific literature. Note that in the previous section, comparisons with the HUD Demonstration data were restricted to abated houses in Denver that were also in the CAP Study. In this section, results for all abated houses for all cities in the HUD Demonstration are used.

The comparison produced two primary results. First, the floor and window stool lead loading levels measured in the CAP Study were generally lower than those in the other studies except the National Survey. Second, the CAP Study window channel lead loadings were higher than the clearance levels measured in the HUD Demonstration and the post-abatement levels collected in the Experimental Practices Pilot.

Table 7-2 compares the CAP Study floor dust lead loading results for unabated and abated houses to those measured in the four studies listed above. For each study, the number of

Table 7-2. Descriptive Statistics for Floor Dust Lead Loadings ($\mu g/ft^2$) by Abatement Efficacy Field Study

Study		Unit Type	No. of Samples Collected	Log St.Dev.[1]	10%	25%	Geom. Mean	75%	90%
CAP		Unabated	51	2.12	1.09	5.71	21.38	64.99	289.2
		Abated	187	2.00	1.69	6.73	28.97	104.34	408.6
HUD Demo[2]			1026	1.53	9.31	23.55	66.01	185.06	468.0
National Survey		High XRF[3]	686	1.85	0.14	0.42	1.47	5.13	15.80
		Low XRF[4]	90	1.63	0.06	0.16	0.47	1.41	3.78
Kennedy-Kreiger[5]	Pre-Abate.	Traditional	280	na	na	na	250.8	na	na
		Modified	82	na	na	na	288.0	na	na
	Post	Traditional	271	na	na	na	1440.0	na	na
		Modified	50	na	na	na	650.3	na	na
	Post (6 months)	Traditional	234	na	na	na	315.9	na	na
		Modified	57	na	na	na	315.9	na	na
Kennedy-Kreiger[6]	Pre	Experimental	70	na	na	na	520.26	na	na
	Post	Experimental	70	na	na	na	130.06	na	na
	Post (6 m)	Experimental	63	na	na	na	55.74	na	na

[1] Units are Log($\mu g/ft^2$).

[2] Abated houses from all metropolitan areas in the FHA portion.

[3] Predicted maximum interior or exterior XRF reading at these residences was at least 1.0 mg/cm^2.

[4] Predicted maximum XRF reading at these residences was below 1.0 mg/cm^2.

[5] Farfel and Chisolm (1990).

[6] Farfel and Chisolm (1991).

samples, log standard deviation, geometric mean, and 10th, 25th, 75th, and 90th percentiles are presented. Only the number of samples and geometric means were available for two of the studies reported in the literature. Tables 7-3 and 7-4 provide similar comparisons for window stool and window channel dust lead loadings, respectively.

The HUD Demonstration intended to eliminate lead-based paint from housing environments either by containing the lead-based paint with encapsulation or enclosure methods, or by eliminating the lead-based paint with removal methods (HUD, 1991). Because of the diversity of housing components containing lead-based paint, it was generally true that no single abatement method could be used uniformly throughout a given housing unit. The housing units selected for complete abatement included 169 single-family dwellings from the inventory of FHA repossessed houses in seven urban areas. The clearance (immediately post-abatement) dust wipe lead loading results from these houses were considered in this instance. The tabled results were calculated from all metropolitan areas in the study, not just Denver. The geometric mean floor and window stool lead loadings measured in the HUD Demonstration were higher than those collected in unabated houses in the CAP Study. In contrast, the geometric mean window channel lead loadings were lower in the HUD Demonstration than the CAP Study.

The HUD National Survey was conducted to examine on a national basis the incidence of lead in soil, dust, and paint (HUD, 1990a; EPA, 1995c; EPA, 1995d; EPA, 1995e; data revision Westat, 1993). No abatement procedures were performed. In seeking to represent the pre-1980 housing stock in the U.S., a total of 381 housing units were sampled: 284 privately-owned residences and 97 public housing units. Dust vacuum lead loading results were obtained from a subset (265 houses) of the privately-owned residences sampled and were included in Tables

7-2, 7-3, and 7-4. The houses were partitioned into two groups: the high XRF group with a predicted maximum of interior or

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Table 7-3. Descriptive Statistics for Window Stool Dust Lead Loadings ($\mu g/ft^2$) by Abatement Efficacy Field Study

Study		Unit Type	No. of Samples Collected	Log St.Dev.[1]	10%	25%	Geom. Mean	75%	90%
CAP		Unabated	35	1.93	3.79	9.85	46.90	224.7	571.5
		Abated	78	2.18	7.02	15.43	91.57	467.2	1315.1
HUD Demo[2]			783	1.79	9.03	26.70	89.06	297.1	878.56
National Survey		High XRF[3]	329	2.47	0.18	0.82	4.32	22.77	101.74
		Low XRF[4]	38	2.47	0.05	0.24	1.26	6.68	29.98
Kennedy-Kreiger[5]	Pre-Abate.	Traditional	280	na	na	na	1337.8	na	na
		Modified	82	na	na	na	1802.3	na	na
	Post	Traditional	271	na	na	na	3595.4	na	na
		Modified	50	na	na	na	603.9	na	na
	Post (6 months)	Traditional	234	na	na	na	1542.2	na	na
		Modified	57	na	na	na	1635.1	na	na
Kennedy-Kreiger[6]	Pre	Experimental	70	na	na	na	4608.0	na	na
	Post	Experimental	70	na	na	na	325.2	na	na
	Post (6 m)	Experimental	63	na	na	na	408.8	na	na

[1] Units are Log($\mu g/ft^2$).

[2] Abated houses from all metropolitan areas in the FHA portion.

[3] Predicted maximum interior or exterior XRF reading at these residences was at least 1.0 mg/cm^2.

[4] Predicted maximum XRF reading at these residences was below 1.0 mg/cm^2.

[5] Farfel and Chisolm (1990).

[6] Farfel and Chisolm (1991).

Table 7-4. Descriptive Statistics for Window Channel Dust Lead Loadings ($\mu g/ft^2$) by Abatement Efficacy Field Study

Study		Unit Type	No. of Samples Collected	Log St.Dev.[1]	10%	25%	Geom. Mean	75%	90%
CAP		Unabated	27	2.02	84.16	738.0	2330	12427	20517
		Abated	71	2.33	51.74	510.5	2590	18884	39308
HUD Demo[2]			756	1.93	42.90	138.1	506.2	1856	5973
National Survey		High XRF[3]	142	2.66	2.40	12.08	72.64		2194
		Low XRF[4]	7	3.38	0.38	2.97	28.94	436.72	2193
								282.33	
Kennedy-Kreiger[5]	Pre-Abate.	Traditional	280	na	na	na	15496	na	na
		Modified	82	na	na	na	18274	na	na
	Post	Traditional	271	na	na	na	14354	na	na
		Modified	50	na	na	na	8083	na	na
	Post	Traditional	234	na	na	na	12468	na	na
	(6 months)	Modified	57	na	na	na	24879	na	na
Kennedy-Kreiger[6]	Pre	Experimental	70	na	na	na	29422	na	na
	Post	Experimental	70	na	na	na	938	na	na
	Post (6 m)	Experimental	63	na	na	na	1003	na	na

[1] Units are Log($\mu g/ft^2$).

[2] Abated houses from all metropolitan areas in the FHA portion.

[3] Predicted maximum interior or exterior XRF reading at these residences was at least 1.0 mg/cm^2.

[4] Predicted maximum XRF reading at these residences was below 1.0 mg/cm^2.

[5] Farfel and Chisolm (1990).

[6] Farfel and Chisolm (1991).

exterior XRF levels of at least 1.0 mg/cm^2, and the low XRF group with a predicted maximum of interior and exterior XRF readings of less than 1.0 mg/cm^2. There were 235 houses in the high XRF group and 30 houses in the low XRF group. The unusually low dust lead loadings measured in the National Survey may be misleading, due in part to the sampling apparatus employed. Vacuum versus wipe field testing by EPA (EPA, 1995a) indicated that the vacuum sampling protocol used in the National Survey recovered only about 20% of the lead that would be recovered by a wipe sample. Wipe sample results tended to be less than or equivalent to those from the CAPS vacuum sampler. Hence there is likely to be at least a five fold difference between CAPS vacuum dust results and National Survey vacuum dust results, which would account for some of the differences in lead loadings between the CAP Study and the National Survey.

The Traditional versus Modified Practices Study was performed by Kennedy-Kreiger Institute (Farfel and Chisolm, 1990). Serial dust wipe lead loading measurements were collected from 71 dwellings in Baltimore, Maryland. Samples were collected before, immediately after, and six months after abatement of lead-based paint within the dwellings. Local abatement requirements addressed deteriorated paint on surfaces up to four feet from the floor and all paint on easily accessible "biting" surfaces where lead content of the paint was greater than 0.7 mg/cm^2 by XRF or 0.5 percent by weight. Traditional practices involved only cursory clean-up following the abatement, and allowed a variety of abatement methods to be used. The modified practices called for more substantial clean-up following abatement, and excluded the use of open-flame burning and sanding techniques. Most of the study dwellings were low-income row houses constructed before 1940. The geometric mean floor, window stool, and window channel dust lead loadings in the CAP Study were at least an order of magnitude lower than the geometric mean post-abatement values for both the traditional and modified practices procedures. The incomplete nature of the traditional and modified abatement procedures may explain the resulting high dust lead loadings. Window channels, for example, were not abated as part of these procedures.

The Experimental Practices Pilot Study was also performed by Kennedy-Kreiger Institute (Farfel and Chisolm, 1991). The experimental practices are described as abatement procedures which included, (1) treatment of lead-painted surfaces above and below four feet from the floor; (2) sealing and covering of wooden floors; (3) procedures for containment of dust during abatement; and (4) final cleanup using a high-efficiency particle air (HEPA) vacuum. Dust wipe lead loading samples were collected in six two-story, six-room low income row houses constructed in the 1920's. Measurements were taken before, immediately following, and six months after the abatement procedures occurred. The CAP Study geometric mean lead loading levels measured on floors and window stools were lower than those measured following the experimental abatement procedures. Interestingly, the geometric mean window channel lead loadings in the CAP Study were higher than the post-abatement results in the Experimental Practices Pilot. It should be noted that the CAP Study took place two years after abatement, while the Experimental Practices results were within six months of abatement.

8.0 OUTLIER ANALYSIS

In this section, the outlier analysis is discussed. First is a discussion of the general approach to the analysis, followed by details on how the data were grouped, a description of the outlier analysis procedure used, and a discussion of how the outliers found were handled in the statistical analysis. Data from House 08 (the house for which no pre-sampling XRF measurements were taken), which were excluded from the full statistical analysis, were included in this outlier analysis.

8.1 APPROACH

Formal statistical outlier tests were performed on both the field data and the laboratory QC data. Data were placed into groups for comparable types of samples, and a maximum absolute studentized residual procedure was used to identify potential outliers. When a potential outlier was identified, that value was excluded from the group, and the outlier test was performed again. This procedure was repeated until no additional outliers were detected. After all potential outliers were identified, a list of these samples was sent to the laboratory for rechecking.

8.2 DATA GROUPS

Samples collected from inside the houses were grouped according to the predominant interior abatement method, sampling method (vacuum or wipe) and component (air duct, floor, window channel, field blank, trip blank, etc.). Soil samples and exterior entryway vacuum samples were grouped according to the predominant exterior abatement method. In addition, interior floor samples were split into two groups, those taken from carpeted floors and those taken from uncarpeted floors. Separate outlier analyses were then performed for each group on the natural logarithm of lead loading values, the natural logarithm of lead concentration values, sample concentration values (field blanks only) and net weight values (trip blanks only).

Normally, foundation soil samples were collected from the soil along the foundation of each house. In one case, however, pavement along the foundation required the use of a vacuum cassette to collect two dust samples rather than the usual two soil samples. Additional outlier tests were performed (1) grouping these two samples with foundation soil samples, and (2) grouping these two samples with exterior entryway vacuum samples.

Laboratory QC data were grouped according to type of sample and sample medium. Outlier analyses were then performed on the natural logarithm of the appropriate measurement for each type of sample (spike recovery for spiked samples; amount of lead for method blanks, calibration blanks, and unspiked samples; percent recovery for interference check samples, calibration standards, calibration verification samples and blind reference material samples; and range of spike recovery for duplicate spiked samples).

8.3 THE OUTLIER TEST

The SAS procedure GLM (SAS PC, ver. 6.04) was used to compute the studentized residual for each data value by fitting a "constant" model (i.e., mean value plus error term) to the log-transformed data in each group. The absolute values of the studentized residuals were then compared to the upper .10/n quantile of a t distribution with n-2 degrees of freedom, where n was the number of data values in the group. If the maximum absolute studentized residual was greater than or equal to the .10/n quantile, the corresponding data value was flagged as a potential outlier. The outlier test was then repeated, excluding additional potential outliers, until no more outliers were detected. Table 8-1 lists the field sample outliers found as a result of this test. Table 8-2 lists the laboratory QC sample outliers.

Table 8-1. CAP Study Outliers - Field Samples

Lead Loading Outliers

Instrument Batch	Sample Preparation Batch	Lab ID	Sample Medium	Study ID/ Sample ID	Location	Component	Lead Loading[a] (ug/ft^2)
E04292A	WIO	902924	Dust-Vacuum	28/01	Kitchen	Floor	< 0.34
E05072B	WIR	903347	Dust-Vacuum	96/02	Hall	Floor	2365.43
E05072B	WJB	903556	Dust-Vacuum	19/01	Living Room	Floor	1102.35
E05132A	WJC	903116	Dust-Vacuum	96/01	Hall	Floor	11641.25
E06022A	WJG	902546	Dust-Vacuum	45/07	Kitchen	Floor	1765.38
E07272A	WIZ	903392	Dust-Vacuum	19/02	Living Room	Floor	6745.20
E07272A	WIZ	903769	Dust-Vacuum	21/25	Laundry Room	Floor	7046.70
E08032A	WKF	905079	Dust-Wipe	21/26	Laundry Room	Floor	333.56
E08032A	WKG	905143	Dust-Wipe	57/27	Bathroom #2	Floor	< 2.72

Lead Concentration Outliers

Instrument Batch	Sample Preparation Batch	Lab ID	Sample Medium	Study ID/ Sample ID	Location	Component	Lead Concentration[a] (ug/g)
E04272A	WIL	902564	Dust-Vacuum	17/13	Front	Outside Entryway	8.84
E04292A	WIL	902761	Dust-Vacuum	94/12	Hall	Inside Entryway	21.67
E04292A	WIO	903673	Dust-Vacuum	46/05	Bathroom	Air Duct	4623.43
E05072B	WIR	902605	Dust-Vacuum	79/12	Kitchen	Inside Entryway	2723.16
E05072B	WIR	903347	Dust-Vacuum	96/02	Hall	Floor	1724.32
E05072B	WJD	902142	Dust-Vacuum	49/02	Kitchen	Floor	< 4.56
E05072B	WJD	903487	Dust-Vacuum	60/01	Bedroom #1	Floor	< 11.00
E05122B	WJE	902126	Dust-Vacuum	79/14	Back	Outside Entryway	16335.45
E05122B	WJF	902220	Dust-Vacuum	51/02	Bathroom	Floor	13567.76
E05132A	WJC	903116	Dust-Vacuum	96/01	Hall	Floor	6217.62
E05192A	WIQ	904271	Soil	81/17	Back	Foundation	3351.12
E05262A	WIT	904054	Soil	79/16	Back	Entryway	< 4.55
E06022A	WJG	902546	Dust-Vacuum	45/07	Kitchen	Floor	6398.60
E06042A	WJP	902380	Dust-Vacuum	68/10	Dining Room	Air Duct	5644.54
E06112A	WIW	904433	Soil	51/18	Back	Foundation	< 5.49[1]
E06122A	WJR	903291	Dust-Vacuum	72/11	Hall	Inside Entryway	9.65
E06152A	WJV	903089	Dust-Vacuum	68/12	Kitchen	Inside Entryway	1200.39
E06292A	WKB	902955	Dust-Vacuum	80/11	Living Room	Inside Entryway	5332.00
E06292A	WKB	903020	Dust-Vacuum	03/04	Bathroom	Window Stool	48271.93
E06292A	WKB	903163	Dust-Vacuum	31/07	Bathroom #2	Floor	1.71
E07212A	WJG	902953	Dust-Vacuum	51/01	Bathroom	Floor	12186.30
E07212A	WJR	902169	Dust-Vacuum	19/12	Kitchen	Inside Entryway	2293.62
E08242A	WJA	904397	Soil	53/19	Left	Boundary	1074.24[2]
E08242A	WJX	902275	Dust-Vacuum	10/12	Kitchen	Inside Entryway	9.24

aThe symbol "<" means that the sample had lead below the instrument detection limit (IDL), and based on the IDL the level of lead present is less than the value given after the "<" symbol.

Table 8-1. Continued

Field Blank Outliers

Instrument Batch	Sample Preparation Batch	Lab ID	Sample Medium	Study ID/ Sample ID	Location	Component	Amount of Lead[a] (ug/sample)
E04292A	WIO	902825	Dust-Vacuum	18/06	Kitchen	Field Blank	< 0.344
E05272A	WIV	904161	Soil	70/22	Front	Field Blank	35.638
E06112A	WIW	904333	Soil	50/22	Right	Field Blank	271.625[3]
E06152A	WJU	903654	Dust-Vacuum	07/06	Living Room	Field Blank	2.682
E08032A	WKG	905133	Dust-Wipe	94/28	Kitchen	Field Blank	35.445
E08242A	WIT	904183	Soil	99/22	Front	Field Blank	< 1.197

Trip Blank Outliers

Instrument Batch	Lab ID	Sample Medium	Study ID/ Sample ID	Location	Component	Sample Weight (g)
TRIPBLNK	902217	Dust-Vacuum	19/23	Bedroom #1	Trip Blank	-0.0052
TRIPBLNK	902516	Dust-Vacuum	90/23	In Van	Trip Blank	0.0051
TRIPBLNK	902964	Dust-Vacuum	40/23	Living Room	Trip Blank	0.0002
TRIPBLNK	903144	Dust-Vacuum	07/23	Living Room	Trip Blank	0.0007
TRIPBLNK	903146	Dust-Vacuum	65/23	Living Room	Trip Blank	0.0009
TRIPBLNK	903722	Dust-Vacuum	55/23	Living Room	Trip Blank	0.0015

aThe symbol "<" means that the sample had lead below the instrument detection limit (IDL), and based on the IDL the level of lead present is less than the value given after the "<" symbol.

[1]Value subsequently corrected to 271.625 µg/g - no longer an outlier.
[2]Value subsequently corrected to 1072.76 µg/g - still an outlier.
[3]Value subsequently corrected to <5.49 - no longer an outlier.

Table 8-2. CAP Study Outliers - Laboratory QC Samples

Spike Recovery Outliers

Instrument Batch	Sample Preparation Batch	Sample ID	Run Number	Sample Type Flag	Spike % Recovery
E04272A	WIL	903695	102	2	128.5
E04272A	WIL	903701	104	3	134.0
E05042A	WIR	903551	31	2	104.1
E05042A	WIR	903555	33	3	104.0
E05072B	WJB	903604	34	2	101.5
E05072B	WJB	903597	42	3	101.5
E05072B	WJD	903584	116	2	97.8
E05072B	WJD	903753	118	3	97.9
E05122B	WJE	903454	110	2	101.2
E05122B	WJE	903484	112	3	101.2
E05192A	WIP	904266SPD	33	3	130.9
E05272A	WJO	903360	115	2	98.5
E05272A	WJO	903628	116	3	98.4
E06042A	WJP	903320	29	2	100.6
E06042A	WJP	903321	30	3	100.3
E07142A	WKF	905240	45	2	99.2
E07212A	WJC	903546	234	3	113.7
E07272A	WKJ	903303	148	2	108.5
E07272A	WKJ	903079	149	3	109.0

Method Blank Outliers

Instrument Batch	Sample Preparation Batch	Sample ID	Run Number	Sample Type Flag	Amount of Lead[a] (µg/sample)
E07272A	WIZ	MB1	38	4	<4.0202
E07272A	WIZ	MB2	39	4	<4.0202
E07272A	WKJ	MB1	116	4	4.0380
E07272A	WKJ	MB2	142	4	20.6810

[a] The symbol "<" means that the sample had lead below the instrument detection limit (IDL), and based on the IDL the level of lead present is less than the value given after the "<" symbol.

Table 8-2. Continued

Reference Material Recovery Outliers

Instrument Batch	Sample Preparation Batch	Sample ID	Run Number	Sample Type Flag	Reference Material % Recovery
E06292A	WIX	904326	181	5	114.8
E07302A	WKJ	902699	156	5	34.4
E08212A	WKJ	902699	28	5	22.9
E08212A	WIZ	902731	29	5	27.0

Continuing Calibration Blank Outliers

Instrument Batch	Sample Preparation Batch	Sample ID	Run Number	Sample Type Flag	Amount of Lead (µg/ml)
E05152A	WIK	CCB	44	9	0.0130
E05152A	WIK	CCB	93	9	0.0111
E08182A	REF	CCB	55	9	0.0004

Often, the minimum and/or maximum data values in a group were flagged as outliers by the test described above. If the minimum and maximum values in a group were not flagged, they were nevertheless included in Tables 8-1 and 8-2 as being potential outliers. Of the 838 lead loading values reported, nine (1%) were listed as potential outliers. This includes 7 out of 770 vacuum samples and 2 out of 68 wipe samples. Of the 1124 lead concentrations reported, 24 (2%) were listed as potential outliers. This includes 20 out of 770 vacuum samples and 4 out of 354 soil samples. Of the 139 field blanks, six (4%) were listed as potential outliers, and of the 53 trip blanks, six (11%) were listed as potential outliers.

8.4 RESOLUTION OF OUTLIER QUESTIONS

Tables 8-1 and 8-2 were sent to the laboratory for review. This review resulted in corrections to three of the identified field sample outliers (as indicated in footnotes to Table 8-1) and two other values which had not been identified as outliers. Two of the three outliers had similar laboratory sample ID numbers which were inadvertently switched during instrument analysis. The third outlier and the two other values were originally reported with incorrect sample weights due to re-preparation of a batch of samples. No errors were found in the reporting of the laboratory QC sample data.

8.5 DATA CERTIFICATION

In addition to the investigation of statistical outliers, an audit of the data management system was performed. In this audit 53 (out of 1413) field samples and 28 (out of 1295) laboratory QC samples were randomly selected, and all of the information in the CAPS data base for these samples was exhaustively checked against the appropriate original data sources, that is, the origninal field data collection forms, laboratory analytical data reports, and HUD Demonstration data sets. The random selection of audit samples was constrained so that all 52 housing units, all 28 laboratory analytical batches, and all different sample types were proportionately represented.

The data management audit found no problems with any of the key data used in the statistical analysis to draw conclusions for the CAP Study. Minor problems with other information in the CAPS data base were discovered by the data management audit, such as spelling and grammatical problems in comments on field forms. These minor problems did not affect data collected from the field, nor the statistical analysis.

The laboratory which was responsible for the chemical analysis of the data used in this study also performed a quality assurance audit of the data produced by the laboratory. A total of 17.6 percent of the total samples in each batch were selected for audit. Field samples, lab QC samples, and instrument calibration samples were included. In all, 692 samples were audited, and 28 samples were found to have errors. This provides an estimated error rate of 4.05 percent, with a 95 percent confidence interval of 2.58 to 5.51 percent. The distribution of errors was as follows:

- 8 mistakes in sample identification numbers,
- 6 mistakes in dilution factors,
- 7 mistakes in weights,
- 2 mistakes in instrumental response,
- 2 mistakes in entering information, and
- 3 calculation mistakes.

The error rate found suggests an that 129 errors may be present in the remaining 3197 samples not audited. However, 100 percent verifications were later performed for sample identification numbers and instrumental responses, correcting additional errors of these types. Although 100 percent verification was not found to perfectly correct all errors, the number of oversights is expected to be small.

In light of the 100 percent checks performed on the sample identification numbers and instrumental responses, the revised estimated error rate in the 3197 unaudited samples is 2.75 percent. This implies a total of 88 samples with errors. The upper confidence bound on this estimate is 127 samples. Restricting to field samples results in an estimate of 32 field samples with errors and an upper confidence bound of 46 errors in the field samples.

9.0 STATISTICAL ANALYSIS OF QUALITY CONTROL DATA

To assure that the sampling and analytical protocols employed in the CAP Study were producing data of sufficient quality, a number of different quality control (QC) samples were included in the study design. The intended purpose of each QC sample varied, but each sample type belonged to one of three categories:

1. Field QC Samples, originating in the field, that assess the quality of the sample collection procedures;

2. Sample Preparation QC Samples, originating in the sample preparation laboratory, which examine the preparation of field samples for analysis, and;

3. Instrumental Analysis QC Samples, produced in the instrument analysis laboratory, that evaluate the quantitative analysis of the samples.

These individual categories reflect distinct goals of the QC analysis, and separate steps in the collection and analysis of a sample. From a statistical analysis perspective, however, the QC samples may be partitioned somewhat differently. This partitioning reflects the nature of the parameter considered when assessing a particular QC measure. Specifically, the QC samples are partitioned analytically into three groups: (1) blank samples, (2) recovery samples, and (3) duplicate samples. Table 9-1 below is helpful in considering these two approaches to categorizing the QC results. Each type of QC sample employed in the CAP Study is identified within a particular cell of the table. For example, spiked samples were analyzed as recovery samples, but their results address the quality of the sample preparation procedures. A total of ten QC measures were employed. Detailed results of the statistical analyses performed on these QC measures are reported in the sections that follow by analysis category. Within each category, the implications of the results to each procedure step are discussed.

Table 9-1. QC Sample Categorization Matrix

	Field QC	Sample Preparation QC	Instrument Analysis QC
Blank Samples	• trip blanks • field blanks	• method blanks	• calibration blanks
Recovery Samples		• spikes • blind reference materials	• interferant check standards • calibration verifications
Duplicate Samples	• side-by-sides	• spiked duplicates	

As an overall summary, the following conclusions may be drawn regarding the QC samples:

1. Analysis of the blank samples suggests little if any procedural contamination. The majority of blanks were measured with a lead content below the instrumental level of detection.

2. Despite some procedural problems in their creation and analysis, the results for the recovery samples indicate very good method performance.

3. Spiked duplicate samples created in the laboratory exhibited very good agreement. Side-by-side field samples, on the other hand, suggest significant variability in field sampling. Greater inherent variation was seen in dust samples than in soil samples.

4. There is no significant evidence of a time-based trend in any of the QC samples.

9.1 BLANK SAMPLES

Blank samples are expected, by the nature of their collection and preparation, to contain very little or no lead. In the CAP Study, four types of blank samples were analyzed: trip blanks, field blanks, method blanks, and calibration blanks. For all but the trip blanks, the parameter of interest was the amount of lead (μg) measured for the sample (lead content). For the trip blanks and also for the field blanks, the net weight (g) of the sample was also examined. Evidence of a significant amount of lead in a blank sample would suggest a bias in the results for the regular field samples. As was the case for the regular field data, the lead content of the blanks was assumed to follow a lognormal distribution. The amounts, therefore, were log-transformed before statistical analysis.

9.1.1 Field Quality Control

Trip blanks are vacuum dust cassettes that are weighed in the gravimetric laboratory before and after being transported to the field. They are similar to field blanks, except they are not exposed to the field environment. Trip blanks provide information on the sample weight variability resulting from gravimetric laboratory activities in the absence of field handling. Used in combination with the field blank net weight data, they provide a means of determining the error contribution from the gravimetric laboratory should the net weight data from the field blanks show an unusual result. Accordingly, no lead analysis was performed on trip blanks. One trip blank was generated for each housing unit by selecting, at random, one vacuum dust cassette from all unused cassettes transported to the field.

Descriptive statistics for the net weights measured for both trip and field blanks from the CAP Pilot and CAP Studies are presented in Table 9-2. The number of samples, arithmetic mean, standard deviation, minimum and maximum net weights are presented. Net weight data from trip blanks indicate that gravimetric laboratory processing resulted in a mean net weight gain of 3.5 mg. This gain is about twice as large as that observed during the Pilot study which had a mean net weight gain of 1.8 mg. The weight difference between the CAP Study and CAP Pilot Study can be attributed, in part, to protocol changes made

Table 9-2. Net Weight Results for Trip and Field Blanks

Statistic	CAP Pilot Study		CAP Study	
	Trip Blanks	Field Blanks	Trip Blanks	Field Blanks
Number of Samples	54	9	51*	52
Net Weight Mean (mg)	1.8	2.4	3.5	0.4
Net Weight Standard Deviation (mg)	0.3	0.5	1.2	3.0
Minimum Net Weight (mg)	1.1	1.4	0.2	-6.3
Maximum Net Weight (mg)	2.6	3.0	5.1	5.2

* Excluding one sample identified as an outlier.

in gravimetric processing. The clearance criterion for the determination of cassette stability was increased from ± 1 mg to ± 2 mg. This change was made to reduce the excessive equilibration time required during the pilot study. It was anticipated that the resulting losses in accuracy at low sample weights would be offset by the increased collection efficiency of the sampling system used for dust sample collection. Indeed, the summary in Table 2-1 of the amount of dust collected suggests that the amount of collected dust was sufficiently large to override the weight gain bias resulting from gravimetric laboratory processing.

Field blanks are identical to regular field samples, except that no sample is actually collected. Field blanks provide information on the extent of lead contamination experienced by field samples resulting from a combination of laboratory processing and field handling. In addition, field blanks for cassettes provide information on the sample weight variability resulting from the combination of gravimetric laboratory activities and field handling. Field blanks for vacuum dust, wipe dust (abated houses only), and soil cores were collected for each housing unit.

Field blanks, as opposed to trip blanks, better represent the handling experienced by field samples. Any adjustments to weight data, if required, are best based on field blank net weight data. As shown in Table 2-1, the mean weights of collected dust for field samples are considerably larger than the mean net weight of 0.4 mg measured for the field blanks shown in Table 9-2. No adjustments were made, therefore, to field sample weights of vacuum dust cassettes for the calculation of lead concentration (µg/g) values or lead loading (µg/ft^2) values.

Mean net weights between the trip and field blanks for the CAP Pilot were relatively close as indicated in Table 9-2. However, mean net weights between the trip and field blanks for the CAP Study differ more considerably. The CAP Study data imply that field handling produces a weight reduction in the vacuum dust cassettes. The change between the CAP Pilot and CAP Study data is suspected to be related to a combination of two factors: the protocol changes made in gravimetric processing discussed earlier, and the lack of humidity at the sampling site.

Handling of field blanks exposes the cassettes to the atmosphere at the field site. The procedure for collecting field blanks included the following steps: remove the cassette from the sealed plastic bags, open the cassette casing, insert it into the cyclone sampler, remove it from the sampler, close the cassette casing, and replace the cassette into the sealed plastic bags used for transport. Trip blanks were not removed from their sealed plastic bags in the field. The collection site was in an area known for low humidity; Denver has a dry climate. When opened in a low humidity environment, field blanks would be expected to lose water (and weight) absorbed during equilibration in the gravimetric laboratory. It is suspected that the change in gravimetric clearance criterion did not permit sufficient equilibration time in the gravimetric laboratory to allow the cassettes to gain back all the weight lost during their exposure to the low humidity field environment. This would account for the observed net weight difference between the field and trip blanks. Gravimetric records were reviewed for data to support this supposition. However, no weights were recorded for the first 72 hours after vacuum dust cassettes were placed into the gravimetric laboratory (standard equilibration) and there exist no field humidity data. There are insufficient data available, as a result, to either discount or support the protocol change and humidity effect explanation.

Field blank samples also were measured for lead content. A summary of the field blank lead content results (and in fact, of all the QC results) is presented in Table 9-3. The descriptive statistics reported include the number of samples, number above the instrumental detection limit (IDL), minimum and maximum. When possible, the geometric mean and logarithmic standard deviation for the amount of lead per sample are presented. A 95% upper confidence bound on the 95th percentile for lead content is also provided. For the sake of simplicity, this bound will be referred to as the estimated 95% tolerance bound. These calculations were possible only when a sufficient number of results were above the IDL.

If all results were above the IDL, calculation of the geometric mean and logarithmic standard deviation was routine, and the estimated 95% tolerance bound was determined using an exact procedure for lognormal distributions. In cases where a portion of the results were below the IDL, statistical procedures which recognize these data as censored values were used to estimate the geometric mean and logarithmic standard deviation. A lognormal model was fitted to the data and its parameters estimated. The SAS procedure LIFEREG was utilized in obtaining these estimates. LIFEREG maximizes the log-likelihood function via a ridge stabilized Newton-Raphson algorithm, thereby

Table 9-3. Results of Quality Control Analyses

Quality Control Measure		Parameter Considered	# of Samples[1]	Minimum	Maximum	Geometric Mean	Log Standard Deviation	Lower Tolerance Bound[3]	Upper Tolerance Bound[3]
Field Blanks	Vacuum	Amount (µg)	52 (6)	0.344	2.682	0.228	1.059		2.006
	Wipe		34 (1)	2.723	35.445	na	na		na
	Soil		51 (4)	1.198	35.638	0.067	2.387		9.162
Method Blanks	Vacuum	Amount (µg)	48 (13)	0.468	20.681	0.414	1.135		4.369
	Wipe		6 (1)	2.723	3.975	na	na		na
	Soil		22 (1)	1.276	3.297	na	na		na
Calibration Blanks		Amount (µg)	431 (33)	0.0004	0.068	0.007	0.956		0.041
Blind References	I	% Recovery	38	0.851	1.231	1.016	0.088	0.841	1.227
	II		37	0.344	1.749	1.109	0.274	0.615	1.999
	III		37	0.229	1.131	0.881	0.316	0.447	1.736
ICS		% Recovery	144	0.997	1.211[2]	1.060	0.035	0.993	1.131
Calibration Verifications		% Recovery	274	0.962	1.058	1.014	0.016	0.986	1.043
Spikes	Vacuum	% Recovery	96	0.930	1.428	1.030	0.068	0.904	1.174
	Wipe		12	0.862	1.000	0.926	0.044	0.820	1.044
	Soil		44	0.733	1.309	0.981	0.098	0.799	1.205
Spiked Duplicates	Vacuum	Ratio	48	1.000	1.094	1.031	0.039		1.068
	Wipe		6	1.001	1.151	1.063	0.080		1.238
	Soil		22	1.001	1.308	1.081	0.109		1.227
Side-by-Sides	Vacuum	Ratio (loading)	52	1.027	40.381	2.334	1.110		6.403
	Vacuum	Ratio (conc.)	52	1.022	81.101	2.071	1.129		6.605
	Soil	Ratio (conc.)	51	1.004	4.569	1.296	0.399		1.951

Censored Analysis

[1] The number of samples measured above the instrumental detection limit (IDL) is enclosed in parentheses. If there is no number in parentheses, all samples were measured above the IDL.

[2] This value represents an extra ICS analyzed in the middle of an analysis run from an instrument analysis batch containing no field samples. This batch contained only re-runs of SRM No. 1646 under the conditions described in Section 9.2.1. The next highest ICS, 1.182, was also measured in the same analysis batch.

[3] The lower tolerance bound represents a lower 95 percent confidence bound on the 5th percentile; the upper tolerance bound represents on upper 95 percent confidence bound on the 95th percentile. Where both are provided, combined they represent a 90 percent tolerance interval.

na - The statistic could not be calculated due to the large number of censored samples.

providing maximum likelihood estimates of the log mean and log standard deviation. Further, an approximate procedure was used to calculate the estimated 95% tolerance bound. The “approximate” nature of this statistical procedure was in employing the “censor” estimates for log mean and log standard deviation in calculating a traditional 95% tolerance bound. Since this procedure did not include an adjustment to the bounds reflecting censored data, the estimated tolerance bound is approximate.

The data for field blank samples, and other blank samples, are illustrated in Figure 9-1. The amount of lead (µg) found in each blank sample is plotted by sample type. Different plotting symbols are used to indicate whether the result was above the IDL or below, in which case the detection limit is plotted. In those instances where an estimated tolerance could be calculated, the estimated 95% tolerance bound is illustrated in the figure by a bar which has the bound as its upper value.

Most of the field blanks generated for each sample type were below the IDL: more than 88% of the vacuum dust samples were, as well as more than 97% of the wipe dust samples, and more than 92% of the soil samples. No field blank result exceeded five times the average IDL measured during the analysis activities (0.037 µg of lead per mL). Geometric means for all three sample types are less than this IDL mean. These data suggest that no lead contamination occurred during field sample activities.

9.1.2 <u>Sample Prep Quality Control</u>

Method blanks are blank samples generated in the laboratory during sample preparation activities. They are processed in a manner identical to field samples except that no sample material or sample medium is present in the container used for sample digestion. Method blanks provide information on the potential lead contamination experienced by field samples resulting solely from laboratory processing. Method blanks were generated at a

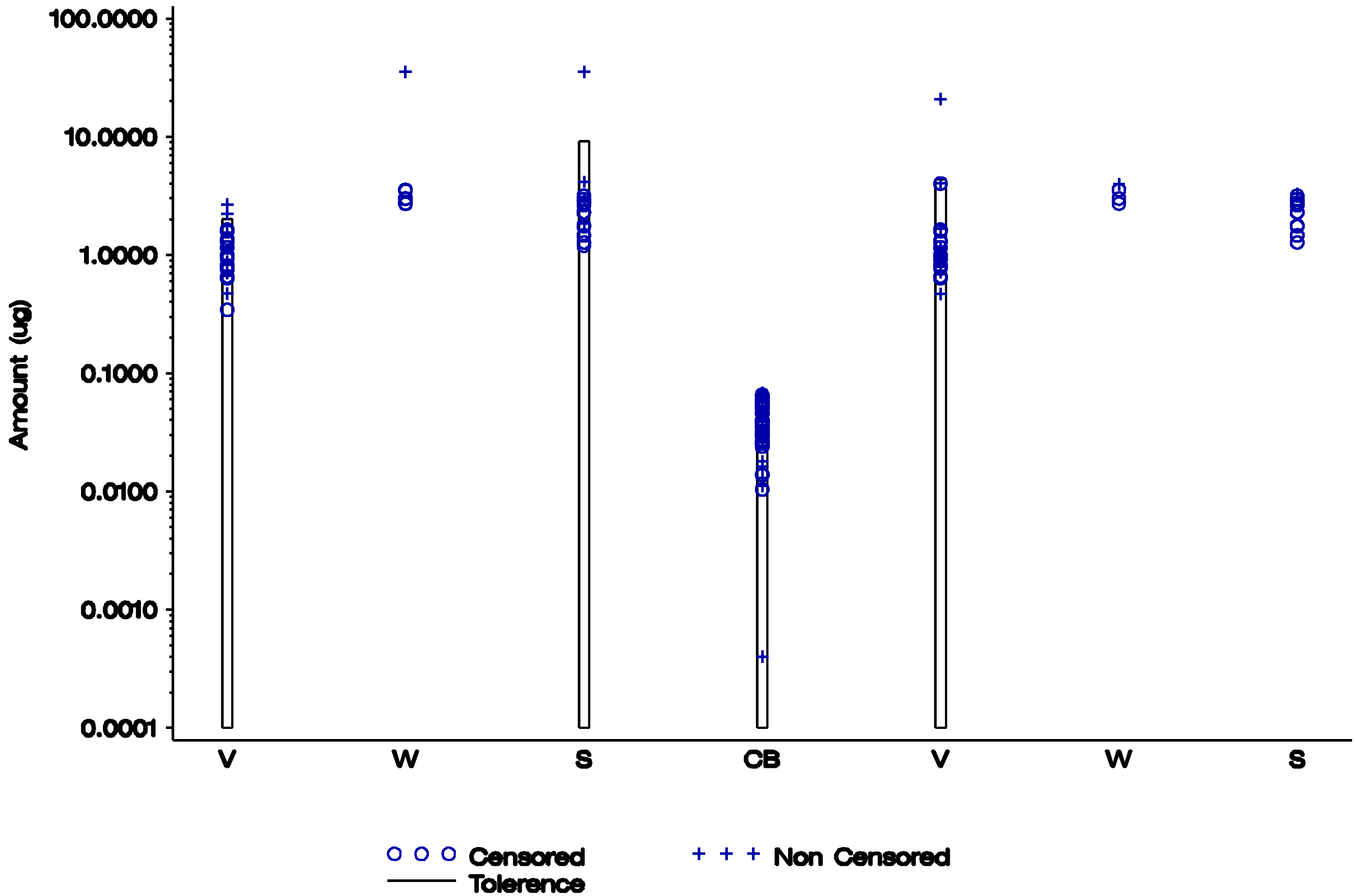

Figure 9-1. Individual measurements and tolerance bounds for µg lead/sample in blank samples.

frequency of two samples per batch of approximately 40 field samples.

A summary of the method blank results is presented in Table 9-3 and presented graphically in Figure 9-1. These results were obtained using the same procedures outlined for field blanks. All method blank data met the data quality objective of lead levels less than 10 times the IDL. Most of the method blanks generated for each sample type were below the IDL: 72% of the vacuum dust samples, 83% of the wipe dust samples, and 95% of the soil samples. In fact, a geometric mean, log standard deviation, and approximate 95% tolerance bound could only be calculated for the vacuum cassettes. Only one method blank result exceeded five times the average IDL measured during the analysis activities (0.037 µg of lead per mL). This method blank was one of two in a sample preparation batch which contained only high sample weight vacuum dust samples with a minimum field sample weight of 4 grams each. This method blank, with a measured lead level near six times the instrumental detection limit, was insignificant with respect to the lead levels within the batch. The other method blank in this high sample weight batch was less than the IDL. These data indicate no lead contamination occurred during laboratory processing of field samples.

9.1.3 Instrumental Analysis Quality Control

Calibration blanks were analyzed along with field samples to assure adequate instrument performance during lead determinations. They are useful in assessing any changes in instrument performance which may affect the estimated lead concentrations reported for regular field samples. Descriptive statistics summarizing the results for calibration blanks are presented in Table 9-3. The individual results and their approximate 95% tolerance bound are portrayed in Figure 9-1. As with the field blank results, the geometric mean, log standard deviation, and approximate 95% tolerance bound are adjusted to reflect the censored nature of many of the results. Greater than

92% of the calibration blanks, which included both initial and continuing calibration blanks, were below the IDL. The maximum lead concentration measured for any calibration blank was less than two times the average IDL for all instrumental analysis runs (0.037 µg of lead per mL). Their geometric mean was well below the average IDL. These results suggest that the field sample results are free from any significant bias caused by carryover.

9.2 <u>RECOVERY SAMPLES</u>

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Recovery samples are prepared to contain a known total amount of lead or to have had a known amount of lead added (spiked). Four types of recovery samples were incorporated into the design of the CAP Study: blind reference material samples, spiked samples, calibration verification samples, and interferant check standards (ICS). The parameter of interest was the ratio of the amount of lead measured for the sample (lead content) to the known amount of lead in the sample. This ratio should be approximately one, and when multiplied by 100 is commonly referred to as the percent recovery. Percent recovery values over 100% indicate a measured value exceeding the known amount of lead in the sample and values under 100% indicate a measured value below the known amount. Spiked soil samples were slightly different in that the spike was added to a sample already containing a measureable amount of lead. The percent recovery value is assumed to follow a lognormal distribution. If the geometric mean of the lognormal distribution is 100%, this is an indication that lead is over-recovered half the time and under-recovered half the time.

Normally, there is a difference between blind reference material samples and spiked samples. Blind reference samples are created by adding a known amount of lead to a blank sample, while spiked samples are created by adding a known amount of lead to a split field sample. These procedures were utilized with the soil samples. In the case of dust samples, blank cassettes and clean wipes were used for the blind reference material samples and for the spiked samples, and there were no split dust samples involved in the creation of the spiked dust samples. Split dust samples were not attempted because of the difficulty in dividing dust samples in a homogenous manner. Hence, the samples labelled as dust spiked samples were made the same way as the samples labelled as dust blind reference material samples. Spiked samples and blind reference samples were inserted into the batch processing stream to monitor the performance of the chemical analysis.

9.2.1 <u>Sample Preparation Quality Control</u>

Spiked samples were blank samples or regular field soil samples fortified with known levels of lead prior to sample preparation activities, and processed in a manner identical to field samples. They provided lead recovery information for assessing the accuracy and precision of field sample data through sample preparation and analysis activities. Spiked samples were generated at a frequency of four (two spikes and two spiked duplicates) per batch of approximately 40 field samples.

As is noted earlier, spiked soil samples were prepared and analyzed somewhat differently from vacuum and wipe dust spikes. Whereas spiked cassette and wipe samples involved spiking a known amount of lead into a blank, spiked soil samples were created by spiking a regular soil sample with a known amount of lead. For cassette and wipe spikes, the ratio of measured amount to known spiking amount was considered (percent recovery). However, since a soil spike sample already contained some lead, a different calculation of percent recovery was required. Specifically, the spiked soil percent recovery was determined as,

$$\frac{\begin{bmatrix} measured\ \mu g\ lead \\ for\ spiked\ sample \end{bmatrix} - \begin{bmatrix} measured\ \mu g\ lead \\ for\ unspiked\ sample \end{bmatrix}}{\mu g\ lead\ for\ spike} * 100.$$

Use of spike data to assess the accuracy and precision achieved for field samples is partially dependent on the matrix matching between the QC sample and field sample. This is because data generated from a given analytical processing scheme are generally matrix sensitive. In the case of soil samples, the matrix matching was very good, because unspiked and spiked samples were generated from splits of homogenized soil samples. Spiked sample data for soils, therefore, were expected to closely mimic that of the field samples. However, as noted earlier, blank cassettes and wipes were used for the unspiked and spiked samples for dust. As a result, the spiked sample QC data for dust samples may be less useful than the spiked sample QC data generated for soils. Still, the spiked sample QC data do provide an adequate measure of the degree of successful execution of the analytical methodology. The sample preparation and analysis methodology is procedurally very similar to methods commonly used and verified successfully for many different types of environmental samples. The spiked sample QC data for dust samples generated during this project are still useful in estimating of precision and accuracy for field samples.

A summary of the spiked sample results is presented in Table 9-3. Descriptive statistics presented include the number of samples, minimum, maximum, geometric mean, and log standard deviation. In addition, an estimated central 90% tolerance interval was calculated using an exact procedure for lognormal data. This interval was derived from a 95% upper confidence bound on the 95th percentile and a 95% lower confidence bound on the 5th percentile. Performance-Control charts showing individual spiked sample recovery data are shown for each sample type in Figures D-1, D-2, and D-3 of Appendix D.

The data for all recovery samples, including the spiked samples, are illustrated in Figure 9-2. The individual percent recovery results for each type of recovery sample are plotted. The estimated central 90% tolerance interval is presented in the figure by a bar extending from the lower confidence bound on the

5th percentile to the upper confidence bound on the 95th percentile.

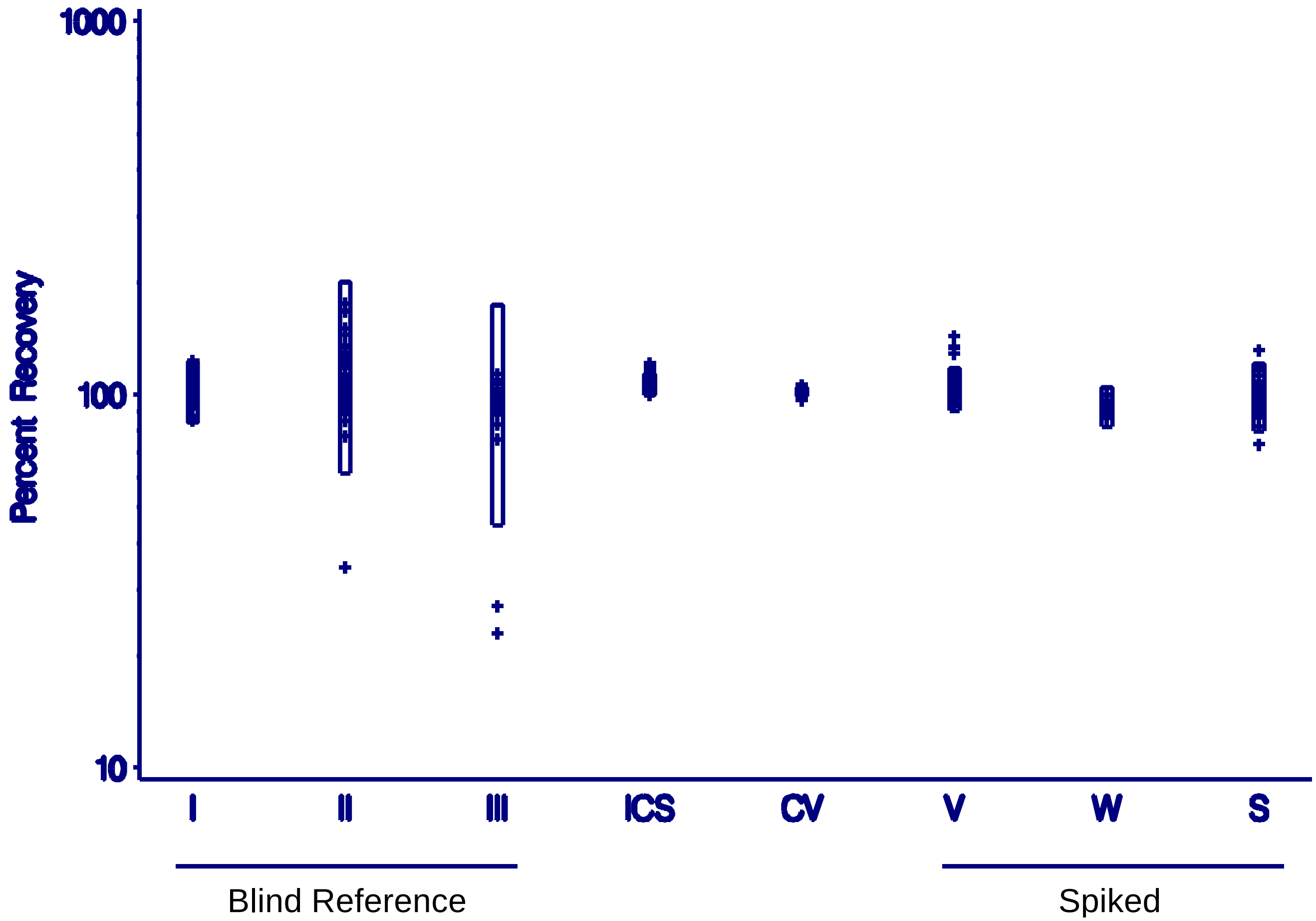

Figure 9-2. Individual measurements and tolerance bounds for percent recovery in recovery samples.

Spiked sample recoveries for all but four data points met the data quality objectives of accuracy of ±20% from the true spiked value. Three of these four points were the result of a spiking error. Specifically, the samples were spiked 10 times less than planned. This error produced measurements approaching both the IDL and background lead levels detected in blankcassettes used in the generation of the spiked samples. Accurate determination of spike recoveries under such conditions is difficult and is not anticipated to be reflective of performance related to field samples. The other data point (soil sample) was only slightly outside the data quality objective (130.9%). Geometric means for all three sample types are within ±10% of the true spiked amount. The estimated tolerance intervals for all three media contain 100% or complete recovery. These data imply that accuracy for field samples was good and well within data quality objectives.

Blind reference material samples were generated by placing known quantities of NIST standard reference materials (SRMs) into blank samples and inserting them into the sample batches in a blind manner prior to sample preparation activities. These reference materials were processed by the laboratory in the same way as the field samples. Their results provide lead recovery information that can be used as an assessment of accuracy of field sample data as determined by sample preparation and analysis activities. The blind nature of the insertion into the sample processing stream helped provide QC data unbiased by laboratory activities. Blind reference materials were generated at a frequency of two (one each of two different materials) per batch of approximately 40 field samples.

As was discussed for the spiked QC samples earlier, matrix matching is an important determinant of the usefulness of QC samples in assessing the accuracy achieved for regular field samples. In general, reference materials are included in an analysis scheme to help provide higher confidence in the accuracy of field sample data than can be obtained using only spiked

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samples. Unfortunately when this study was initiated, no suitable dust or soil SRMs were available. Two SRMs were chosen as the best available approximations to the anticipated matrices of the field samples. The matching was achieved with respect to general matrix components and anticipated lead levels. These were NIST SRM No. 2704 Buffalo River Sediment and NIST SRM No. 1646 Estuarine Sediment. Given the limitations of the matrix match, some caution is appropriate in extending the accuracy results of these reference materials. These data, combined with the spiked results, still do provide reasonable confidence that analytical methodologies were carried out as planned.

Performance-Control charts, showing the percent recovery of lead from the two blind reference materials, are shown for each sample type in Figures D-4, D-5, and D-6. Blind reference material recoveries for NIST SRM No. 2704 met the data quality objectives for accuracy of ±30% from the true spiked value. Recoveries for NIST SRM No. 1646, however, were sporadic. Eight of 37 data points were outside data quality objectives. Investigation into these recovery problems suggested they were related to corrections for spectral interferences during instrumental analysis measurements. SRM No. 1646 has a low lead concentration (28.2 µg/g) combined with high levels of other metals such as iron. The iron-to-lead ratio is over 1000 to 1. In order to correct for potential iron interferences, the analyst conducting the instrumental measurements must perform serial dilution of all digests to get iron levels within the calibration range of the ICP instrument. For field samples, extra dilutions were rarely needed, which indicates limits to the ability of SRM No. 1646 to mimic field sample matrices. For the blind SRM No. 1646 reference materials, extra dilution was always required. This extra dilution pushed the measurable lead level down to within a few multiples of the instrumental detection limit where measurement variance increases relative to digests with higher concentrations of lead. The result of these extra dilutions were the sporadically poor recoveries seen for SRM No. 1646.

The sporadic recoveries for SRM No. 1646 were verified by reanalyzing the original digests using the ICP-AES reconfigured to extend the linear range of the instrument for detecting iron. In this way the extra dilution requirement was avoided. The results of the measurements are plotted as the DF=1 data points in the Performance-Control charts shown. Using the reconfigured instrument, all but two blind reference material recoveries for NIST SRM No. 1646 met the data quality objectives of accuracy of ±30% from the true spiked value. The remaining two points were associated with extra high weight sample batches that required a sample preparation protocol change. The change resulted in a four-fold increase in final digestion volume. The increase, in turn, reduced lead levels to values close to the IDL.

Blind reference material results, shown in Table 9-3, are partitioned into three groups depending upon the standard reference material used. Results for SRM No. 2704 are identified as Group I, while the original analysis results for SRM No. 1646 are identified as Group II. The results of the reanalysis of SRM No. 1646 (data points plotted in the figures as DF=1) are identified as group III. These results are illustrated in Figure 9-2. The geometric means were within ±12% of the NIST certified value. The estimated central 90% tolerance intervals all contain 100% recovery. Even with the matrix match limitations for these SRMs, these data imply that accuracy for field samples was good and well within data quality objectives.

9.2.2 <u>Instrumental Analysis Quality Control</u>

Calibration verification samples were analyzed along with field samples during instrumental measurement activities to verify calibration standard levels and monitor drift of instrument response. A summary of lead results for calibration verification samples is shown in Table 9-3 and Figure 9-2. These statistics are calculated using the same procedures described for spiked samples. All calibration verification results met design specifications. In addition, the estimated central 90% tolerance interval is narrow and contains 100%. It seems reasonable to conclude that the field sample results are free from any significant bias caused by instrumental drift.

Interference check standards (ICS) were used to verify accurate analyte response in the presence of possible spectral interferences from other analytes present in the sample. A summary of lead results for ICS is available in Table 9-3 and Figure 9-2. As with the calibration verifications, the estimated central 90% tolerance interval is remarkably narrow and contains 100%. There is no evidence of any significant bias in the regular field sample results caused by commonly encountered interferences.

9.3 DUPLICATE SAMPLES

Duplicate samples are expected to be have similar lead content either because they were collected side-by-side in the field or because they were created to be comparable in the laboratory. In both cases, such samples were analyzed one after the other in the same analytical batch. The analytical result of interest for each pair of duplicate samples was the ratio of the larger measured lead result to the smaller measured lead result. This ratio has a minimum value of one. The log of this ratio was assumed to follow the absolute value of a normal distribution with mean zero and standard deviation F. In the CAP Study, two types of duplicate samples were examined: side-by-side samples collected in the field, and spiked duplicate samples created in the sample preparation laboratory.

9.3.1 Field Quality Control

Side-by-sides were included to determine variability due to the sample collection process; however, this source of variability will also be confounded with short-scale variations attributable to nearby sampling locations within a room or local sampling area. Side-by-sides were collected for dust vacuum and soil core samples. A pair of dust and soil duplicates were collected at each housing unit surveyed.

Table 9-3 reports descriptive statistics for the side-by-side samples. The statistics presented are the number of samples collected, minimum ratio, maximum ratio, geometric mean ratio, and log standard deviation. An estimated 95% tolerance bound was also calculated, using an exact procedure for the distribution assumed for the log transformed ratio.

The side-by-side results are illustrated in Figure 9-3. The ratio for each pair of samples is plotted by sample type. The estimated 95% tolerance bound is portrayed in the figure by a bar extending from a value of one up to the tolerance bound.

The soil side-by-sides exhibit better agreement than the vacuum dust pairs. Their geometric mean was approximately 40% smaller than that for the paired dust vacuum lead concentrations. The inherent variability between field samples, however, is evident in these results. Despite being collected side-by-side, a number of the pairs were measured to have very different lead contents. This disparity is reflected in the higher ratios and relatively large estimated tolerance bounds.

9.3.2 Sample Preparation Quality Control

Spiked duplicate samples originate in the sample preparation laboratory and are developed with identical lead content. Each pair is derived from two identical spiked samples. The spiked sample results are presented in Section 9.2.1 where a more detailed presentation of their development is available. Spiked duplicates were generated at a frequency of two pair (two spikes and two spiked duplicates) per batch of approximately 40 field samples.

A summary of the spiked duplicate sample results is presented in Table 9-3. This summary is portrayed graphically in Figure 9-3. The descriptive statistics are the same as those developed for the field side-by-side samples. Performance-4

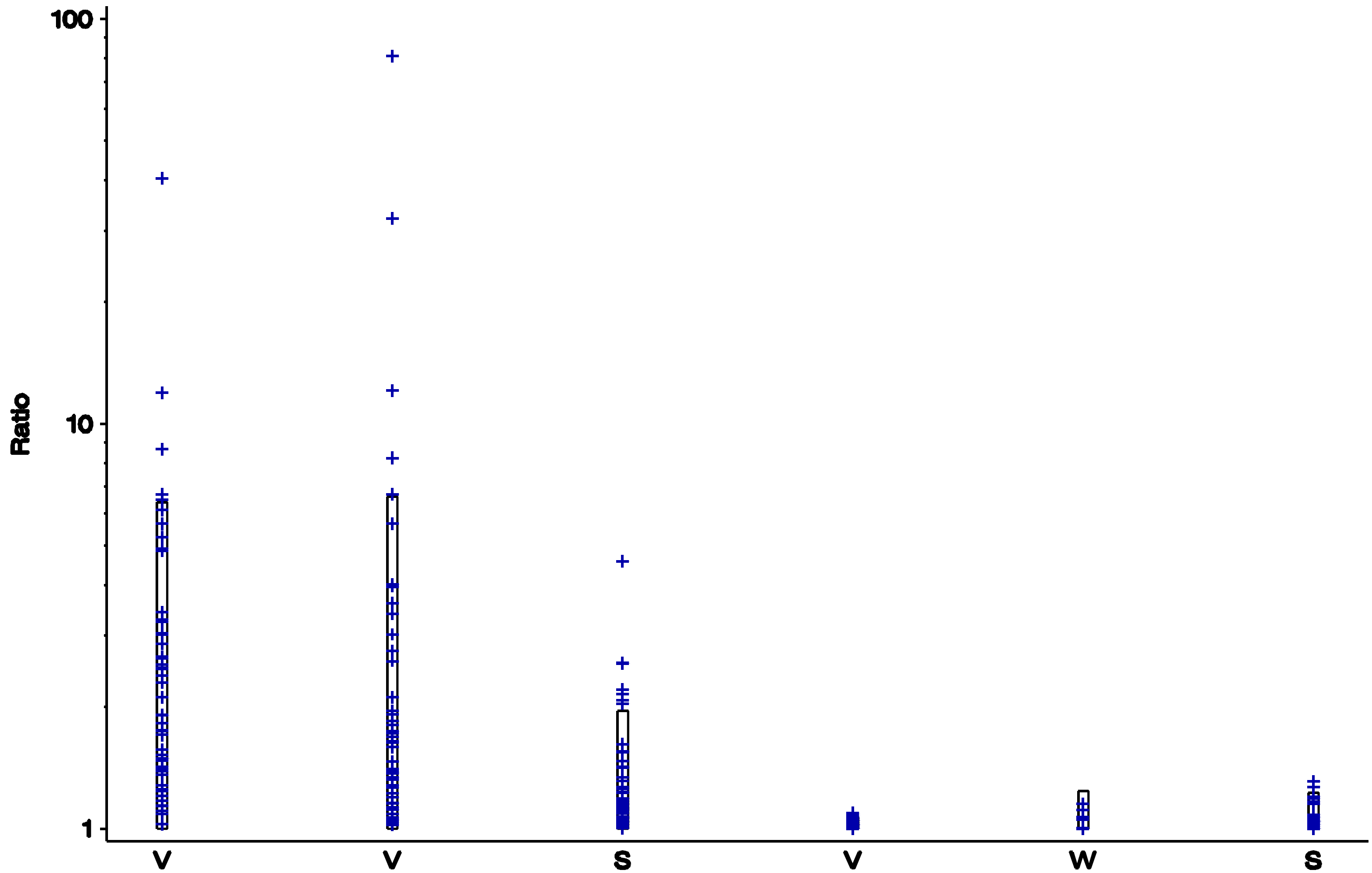

Figure 9-3. Individual measurements and tolerance bounds for the ratio of duplicate samples.

Control charts showing the range of spiked sample and spiked sample duplicate pairs are shown for each sample type in Figures D-7, D-8, and D-9.

The range of spiked duplicate percent recoveries were tighter for dust samples than for soil samples. This is not surprising given the sampling protocol. Recall that spiked blanks were employed for dusts, since cassettes and wipes could not be split homogeneously, and regular field sample splits were utilized for soils (see Section 9.2.1). The ranges observed for soils imply that the 0.5 gram nominal sample weight used for sample preparation may not be sufficient to overcome some heterogeneity apparently still present in the dried, sieved, and homogenized soil samples used for analysis. Figure D-9 shows that the range for four of the spiked duplicate soil sample pairs was above the control limit. Still, the geometric means are close to one and the estimated 95% tolerance bounds are not unreasonably large. The results do suggest good agreement between the spiked duplicate samples.

9.4 TIME TREND ANALYSES

The extensive samples collected in the CAP Study required laboratory analyses which spanned several months. One natural question, therefore, was whether any trend across time was apparent in the samples. Specifically, is there a time-based bias in the sampling results? The QC samples, expected to demonstrate consistent sampling results, are ideal for this examination.

The individual results for each of the QC measures outlined above were plotted using a common frame of reference. Each QC sample was plotted according to the instrument analysis batch it was included in, and its run number within that batch. The instrument batches were ordered based on the time they were processed. For each QC sample type, the appropriate parameter was displayed for the individual results. The measured amount of lead (µg), for example, was displayed for the 52 vacuum dust field blank results.

An examination of these plots suggested no evidence of time trends, except for the soil field blank and method blank results. Recall that more than 92% of the soil field blank results were censored, as were 95% of the soil method blanks. In the results, censored samples are set equal to the instrumental detection limit. Furthermore, these blanks were all analyzed using the same dilution factor (50 mL). Their apparent time trends were determined, therefore, to be a function of the IDLs for the instrument batches containing the soil samples. Figure 9-4 presents the available IDL results for each instrument batch. Those batches which included soil samples are identified as circles. Note that they do exhibit an apparent quadratic trend across time. The IDLs considered as a whole, in contrast, show no evidence of a trend. To assess the significance of the apparent trend in the soil IDLs, quadratic equations were fit to all the IDLs and only to those including soil samples. The two resulting fits were not significantly different (p=0.13). Given the apparent randomness exhibited by the IDLs, there is no evidence of a time trend in the soil field or method blank results.

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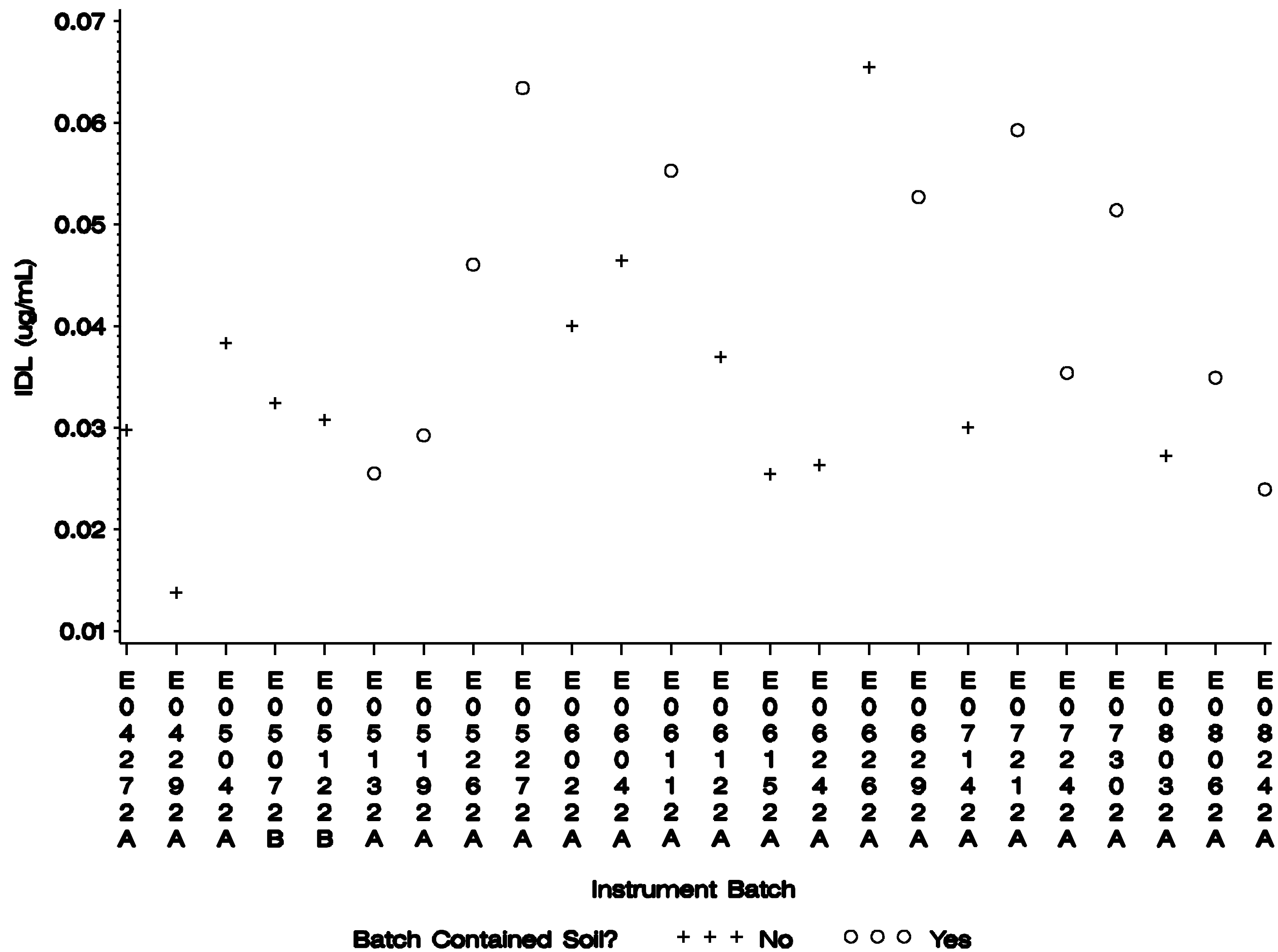

Figure 9-4. Time trend analyses in instrumental detection level by instrument batch.

APPENDIX E

Summary of Interview Results

SUMMARY OF INTERVIEW RESULTS

	A	U	T
1. How many people live in this household?	3.5	3.6	3.6
2. How many of these household members are			
a. over 18 years of age?	2.2	2.1	2.2
b. between 7 and 17 years of age?	0.7	0.7	0.7
c. under 7 years of age?	0.6	0.7	0.6
3. Do you, or another member of the household, own this house?	53%	47%	51%
4a. What Year was this house built?*	1926	1943	1932
4b. How many months has your family been living at this address?	9.2	14.5	10.9

5. In the last six months, have you, anyone in your household, or anyone who occasionally lives in this household, worked at any of the jobs I am about to mention? If yes, how many months during the last six months, did someone do this job?

	Number of Houses Affected			Average for Houses with # > 0		
	A	U	T	A	U	T
a. Paint removal including scraping and sanding	2	1	3	1.0	1.0	1.0
b. Building demolition	3	2	5	3.0	1.0	2.2
c. Home remodeling or renovation	4	1	5	1.8	1.0	1.6
d. Welding	1	2	3	6.0	6.0	6.0
e. Plumbing	1	2	3	1.0	3.5	2.7
f. Sandblasting	0	1	1	--	6.0	6.0
g. Auto body work	2	1	3	3.5	6.0	4.3
h. Salvage (i.e., batteries/radiators)	1	2	3	6.0	4.0	4.7
i. Chemical plant work	0	2	2	--	6.0	6.0
j. Glass work	0	2	2	--	6.0	6.0
k. Lead smelter work	1	0	1	6.0	--	6.0
l. Foundry work	0	0	0	--	--	--
m. Oil refinery work	1	0	1	3.0	--	3.0
n. Battery manufacturing plant work	0	0	0	--	--	--
o. Other lead-related industry work	0	0	0	--	--	--

A = Abated, U = Unabated, T = Total
* = Obtain from HUD Demonstration Data, not interview.

	Number of Respondents			Percent Yes		
	A	U	T	A	U	T
6. (Does the person/Do the people) working at (this/these) jobs every come home from work wearing (his/her/their) work clothes?	13	2	15	91	75	87
7. (Does the person/Do the people) working at (this/these) jobs ever have (his/her/their) work clothes washed here at your home?	13	2	15	82	75	80

8. In the past month, how many times did you or anyone in your household participate in the following activities while at home?

	A	U	T
Number of respondents	35	17	52

	Number of Times (Average)		
a. Remove paint or varnish from furniture in the house	0.5	0.1	0.4
b. Strip and paint bicycles or cars	0.0	0.4	0.1
c. Soldered pipes or repair plumbing	0.2	0.3	0.2
d. Soldered electronic parts or jewelry	0.1	0.1	0.1
e. Join pieces of stained glass with solder	0.0	0.0	0.0
f. Paint pictures or jewelry with artist's paint	0.0	0.0	0.0
g. Glaze pottery or ceramic objects	0.0	0.0	0.0
h. Perform auto maintenance near the house	0.9	1.9	1.2
i. Mold lead into fishing sinkers, bullets, or other objects	0.0	0.0	0.0

A = Abated, U = Unabated, T = Total

	Number of Respondents			Percent Yes		
	A	U	T	A	U	T
9. In the last (six/NUMBER MONTHS IN Q4) months, have you or anyone else done any remodeling or renovation work in this home that involved removal of walls or paneling or removal of paint from walls, floors, windows, porches or other parts of the house by sanding, scraping or any other method?	35	17	52	29 %	18 %	25%
9. Is there renovation currently being done?*	35	17	52	11 %	0%	8%

	Average		
	A	U	T
10. How many dogs or cats live inside the house, have access to living areas and go outside periodically? CONFIRM THAT ALL 3 CONDITIONS ARE MET. IF 9 OR MORE, CODE 9.	0.54	0.41	0.50

	Number of Respondents			Percent Yes		
11. In the last six months, has the dog or cat:	A	U	T	A	U	T
a. scratched or dug in the carpeting?	11	6	17	46	50	47
b. chewed or ripped off parts of walls or molding?	11	6	17	9	100	6

	Number of Respondents			Average		
12. In the past month, how many times did someone:	A	U	T	A	U	T
a. Vacuum carpeted floors?	31	16	47	15.4	14.8	15.2
b. Vacuum uncarpeted floors?	35	17	52	3.4	1.3	2.7
c. Sweep uncarpeted floors?	35	17	52	16.2	10.3	14.3
d. Wet mop uncarpeted floors?	35	17	52	12.1	8.8	11.1
e. Vacuum furniture or dust furniture with a dust cloth?	35	16	51	8.9	8.6	8.8
f. Wash window sills?	34	15	49	2.1	0.7	1.7
g. Dust window sills with a dust cloth?	34	16	50	2.3	2.7	2.4

A = Abated, U = Unabated, T = Total
* = Based on field sampling crew assessment

APPENDIX F

Sample Size Considerations

Sample Size Considerations

In determining appropriate sample sizes for interior dust sampling, two assumptions were made:

- A single sample of each sample type would be taken in each sampled room, and
- Two abated units would be sampled for every one control unit sampled.

Given these assumptions, the two main sample size considerations were: (1) the number of rooms per unit, and (2) the number of units. Let N denote the number of units and M denote the number of rooms per unit.

The value of M should be chosen to minimize overall sampling and analysis costs. Let C_U denote the overall cost of adding an additional unit to the study and C_R denote the sampling and analysis cost of taking a sample from an additional room in a unit which is already included in the study. Then the optimal number of rooms per unit is

$$M = (C_U/C_R)^{1/2} / (F_U/F_R)$$

where F_U and F_R are the unit-to-unit and within-unit standard deviation values. In Table 3-5, optimal values of M are presented for C_U/C_R from 1 to 10 and F_U/F_R from 0.25 to 2.00 by 0.25.

The ratio of the unit-to-unit standard deviation to the within-unit standard deviation (F_U/F_R) was expected to fall in the range 0.5 to 1.0. The ratio of the cost of adding a house to the cost of taking a sample in an additional room was expected to fall in the range 2 to 3. Therefore, according to Table 3-5, the optimal number of rooms per house was expected to fall in the range 2 to 3. To examine the power of tests of the hypotheses H_1, H_2, and H_3 as a function of the number of units, the number of rooms per house was assumed fixed at M=2.

Table 3-5. Optimum Number of Samples per House to Minimize Cost as a Function of Cost Ratio and Standard Deviation Ratio

C_U/C_R	F_U/F_R							
	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1	4.0	2.0	1.3	1.0	0.8	0.7	0.6	0.5
2	5.7	2.8	1.9	1.4	1.1	0.9	0.8	0.7
3	6.9	3.5	2.3	1.7	1.4	1.2	1.0	0.9
4	8.0	4.0	2.7	2.0	1.6	1.3	1.1	1.0
5	8.9	4.5	3.0	2.2	1.8	1.5	1.3	1.1
6	9.8	4.9	3.3	2.4	2.0	1.6	1.4	1.2
7	10.6	5.3	3.5	2.6	2.1	1.8	1.5	1.3
8	11.3	5.7	3.8	2.8	2.3	1.9	1.6	1.4
9	12.0	6.0	4.0	3.0	2.4	2.0	1.7	1.5
10	12.6	6.3	4.2	3.2	2.5	2.1	1.8	1.6

Tables 3-6, 3-7, and 3-8 present ratios that are detectable with 80 percent power for the hypotheses H_1, H_2, and H_3, respectively. The ratios are presented as a function of the log-standard deviation of the estimated ratio and the total number of units. The middle value of the log-standard deviation was selected by setting the unit-to-unit variance to 0.3 and the within-unit variance to 0.7. These values are typical for the lead concentration measurements in the Pilot Study. The other values of the log-standard deviation are 0.5, 0.75, 1.5 and 2 times the middle value. If the total number of units is 60, then the 40 abated units used to define the typical abated unit are assumed to be the houses sampled.

Table 3-6. Ratio Detectable with 80 Percent Power for the Typical Abated Unit vs. a Control Unit

Total Number of Units (N)	$N^{1/2}$ [LSD[a](Estimated Ratio)][b]				
	1.05	1.58	2.11[c]	3.16	4.22
30	1.71	2.25	2.94	5.04	8.65
36	1.64	2.09	2.68	4.38	7.16
42	1.58	1.98	2.49	3.92	6.19
48	1.53	1.90	2.35	3.59	5.50
54	1.50	1.83	2.23	3.34	4.99
60	1.46	1.77	2.14	3.14	4.60

(a) Log-standard deviation

(b) This value is $(6.40\ F_U^2 + 3.62\ F_E^2)^{1/2}$

(c) Using F_U^2=0.3 and F_E^2=0.7

Table 3-7. Ratio Detectable with 80 Percent Power for the Typical Encapsulation/Enclosure Unit vs. the Typical Removal Unit

Total Number of Units (N)	$N^{1/2}$ [LSD[a](Estimated Ratio)][b]				
	1.42	2.13	2.84[c]	4.25	5.67
30	2.06	2.97	4.26	8.80	18.16
36	1.94	2.70	3.76	7.28	14.11
42	1.84	2.51	3.40	6.28	11.59
48	1.77	2.36	3.15	5.58	9.90
54	1.72	2.25	2.95	5.06	8.68
60	1.67	2.16	2.79	4.65	7.77

(a) Log-standard deviation

(b) This value is $(11.95\ F_U^2 + 6.02\ F_E^2)^{1/2}$

(c) Using F_U^2=0.3 and F_E^2=0.7

Table 3-8. Ratio Detectable with 80 Percent Power for the Typical Abated Room in the Typical Abated Unit vs. a Control Room in the Typical Abated Unit

Total Number of Units (N)	$N^{1/2}$ [LSD[a](Estimated Ratio)][b]				
	0.99	1.49	1.99[c]	2.98	3.98
30	1.66	2.14	2.76	4.59	7.63
36	1.59	2.00	2.53	4.02	6.39
42	1.54	1.90	2.36	3.63	5.57
48	1.49	1.83	2.23	3.34	4.99
54	1.46	1.76	2.13	3.12	4.55
60	1.43	1.71	2.05	2.94	4.21

(a) Log-standard deviation

(b) This value is $(2.23\ \Gamma_U^2 + 4.69\ \Gamma_E^2)^{1/2}$

(c) Using $\Gamma_U^2=0.3$ and $\Gamma_E^2=0.7$

In 20 of the abated units (randomly selected), the room with the largest square footage abated and a control room were selected for sampling. In the other 20 abated units, the two rooms with the largest square footage abated were selected for sampling. If the total number of units is less than 60, then it is assumed that the a representative subset of the 40 abated units are included in the study.

To select the total number of units, it was required that a two-fold difference in lead concentrations between the typical abated unit and a control unit be detectable with 80 percent power. This requirement would allow, for example, soil lead concentrations below the critical range of 500 to 1000 µg/g to be distinguished from soil lead concentrations above the critical range. Examining the center column of Table 3-6 leads to a requirement of the maximum number of 60 units. Current plans call for 60 total units (20 controls, 40 abated). Allowing for some recruitment failures or logistical problems (e.g., not all samples can be collected), multiplicative differences on the order of 2.25 would be detected consistently.

Tables 3-6, 3-7, and 3-8 can be used to assess the impact of changes in the total number of units or changes in the assumed values of the unit-to-unit and within-unit variances.

Table 3-9 presents correlation coefficients that will be detectable with 80 percent power as a function of sample size. The proposed 60 total units would result in correlation coefficients of 0.35 and larger being consistently detected. Correlation coefficients of -0.35 and smaller would also be consistently detected.

Table 3-9. Correlation Coefficient Detectable with 80 Percent Power

Total Number of Units (N)	Detectable Correlation
30	0.49
36	0.45
42	0.42
48	0.39
54	0.37
60	0.35

APPENDIX G

Protocol for Vacuum Sampling of Settled Dust

PROTOCOL FOR VACUUM SAMPLING OF SETTLED DUST

1.0 INTRODUCTION

Vacuum samples of settled dusts will be collected from floors (carpeted or uncarpeted), window stools, window channels, and air ducts as specified by the QAPjP. The vacuum sampling device is the cyclone dust collector as shown in Figure G-1.

Each 1-ft^2 section of the surface to be sampled will be vacuumed in overlapping passes (Figure G-2). A 1-ft^2 template will be used to define and measure the areas to be vacuumed. Smaller, well defined surfaces, such as window channels and stools, will be completely vacuumed without the use of the template. The dimensions of the area will be measured after vacuuming the surface and recorded on the sampling data form.

2.0 SAMPLING EQUIPMENT AND SUPPLIES

- Cyclone dust collectors.
- PVC tubing.
- Preweighed Gelman GN-4, 37-mm, mixed cellulose ester (MCE) filter cassettes (0.8-um pore size).
- PVC nozzles (1", 1/2", and 3/8" in diameter).
- Vacuum sampling kit (one per sample).
- 1-ft^2 teflon templates (full square, square "U" shaped, and "L" shaped).
- Steel measuring tape.
- Screw driver (to pry open filter cassettes and tapping cyclone dust samples, if necessary).
- Tweezers.
- Timing device (stopwatch, timer, or watch with second hand).
- Barcode labels (twelve identical labels per sample with a unique sample number).
- 1-qt and 1-gal ziplock plastic bags.

Figure G-1 Cyclone Dust Collector

Figure G-2 Vacuum Sampling Pattern

- Large plastic bags (white color for unused sampling kits, caramel color or equivalent for used sampling kits, and black or dark green color for trash).

- Field sample logs.

- Sample traceability forms.

- Vinyl gloves (powderless).

- Tyvek shoe coverings.

- Electrical extension cords.

- Electrical outlet converters (two-prong unpolarized outlet to three-prong polarized outlet)

- Wash-a-bye Baby premoistened disposable wipes to clean equipment.

- Spatula.

3.0 VACUUM SAMPLING KITS

Vacuum sampling kits will consist of preweighed (tared) 37-mm Gelman (GN-4) MCE filter cassettes packaged in two plastic ziplock bags. The filter cassette will be contained within a 1-qt ziplock bag (inner bag) which will be packaged inside a 1-gal ziplock bag (outer bag) that also contains identical barcode labels corresponding to the sample number of the filter cassette. The vacuum sampling kits will be prepared by the Sample Custodian. The field team will take possession of the sampling kits by signing the sample traceability record prepared by the Sample Custodian. The package should not be opened until the sampling materials are needed in the field.

4.0 RECEIPT OF SAMPLING KITS

The field team will receive sampling materials from the Sample Custodian via Federal Express. The shipping container will include sampling kits and other items used for sampling (i.e., gloves, disposable wet wipes, mailing labels, trash bags, etc.) that are required for one sampling site. Sample traceability records for the enclosed sampling kits will be included with each shipment.

The field team will check the sample numbers of all sampling kits in the shipment against the sample numbers on the enclosed sample traceability record. A check mark is entered under the corresponding barcode label on the traceability record. The field team will then take possession of the sampling kits by signing and dating the sample traceability record. The kits should be examined for breakage when received in the field but not opened until needed to prevent contamination of the sampling materials.

5.0 VACUUM SAMPLING PROTOCOL

The following protocol will be used to collect vacuum samples of settled dust:

- Don shoe coverings (booties) prior to entering the dwelling.

- For small, well defined surface areas (e.g., window channels, window stools), measure the length and width of the area to be vacuumed. Record these data on the sampling data form. For larger areas, (e.g., floor), a clean, 1-ft^2 template will be used to define and measure the surface area to be vacuumed. If the template cannot be used on upholstery, then area sampled must be measured using a tape measure. Measurements will be made after the sample has been collected.

- Record site location, date, time, sampling location, etc. on the sampling data form (recording of pertinent sampling data will be done by the Battelle team leader).

- Prepare the cyclone dust collector (Figure G-3):

  - Remove the cassette holder plug (at bottom of cyclone sampler case) by unscrewing it. Set the holder plug aside.

  - Remove the three O-rings that hold the dust collector case's top and body together. Set these aside with the holder plug.

  - Separate the dust collector's top from its case.

  - Wipe the inside surfaces of the dust collector's top, case and cassette holder with a "Wash-a-bye Baby" wipes. Use more than one, if necessary.

  - Place the used wipes in a waste container.

  - Reassemble cyclone top and sampler case by placing the top onto the sampler case and affixing the three

O-rings. Be sure the O-ring holders on the top are aligned with those on the sampler case.

- Affix the hand vacuum to the cyclone sampler case as shown in Figure G-3.

Figure G-3. Cyclone Dust Collector, Assembled and Disassembled.

- Remove two barcode labels from the sampling kit and affix one to the field sample log and another to the sample traceability record.

- Don a pair of powerless vinyl gloves prior to handling preweighed filter cassettes. <u>Do not touch the preweighed cassettes with bare hands</u>.

- Remove a prelabeled filter cassette from the sampling kit. Compare the sample number on the cassette with the barcode label numbers. These numbers should all match. If they do not match discard the sampling kit.

- Pry open the top section of the filter cassette (Figure G-4) with a clean flat-edged screw driver or equivalent tool. Carefully remove the top section.

  NOTE: The top section of the cassette is the side with the blue cap over the inlet. The middle retaining ring holds the filter and support pad in place against the bottom section of the cassette (Figure G-4). The retain-ing ring should be inspected to ensure that it is seated tightly against the bottom section. If the middle ring is not secure, the filter may tear during the sampling procedure. The seal between the bottom section of the cassette and the middle ring can be secured by squeezing to two sections firmly between the index fingers and the thumbs of both hands.

- Do not remove the red plug from the outlet located on the bottom section (suction port) of the cassette.

- Store the top section of the cassette inside the inner ziplock bag during sampling to avoid contamination.

- Retrieve the cassette holder plug and insert the filter cassette (top section has been removed) into the cassette holder plug of the cyclone dust collector with the closed end of the filter cassette seated firmly into the cassette holder plug (Figure G-5). Replace the cassette holder plug back into the cyclone holder case by screwing it tightly into the bottom of the holder case.

Figure G-4. Filter Cassette Assembly (Used for Dust Collection)

Figure G-5. Placement of Filter Cassette into Cyclone Dust Collector

- Retrieve a clean 90° elbow and a clean 1-in. ID nozzle from their containers. Attach the elbow (Figure G-6) to the sampler case's 1-in. inlet.

- Place the 1-in. ID nozzle into the open end of the 90° elbow (Figure G-6).

- Position the nozzle and the sample case vertically as shown in Figure G-6.

  NOTE: If a 1/2-in. or 3/8-in. ID nozzle is used, first insert the adapter plug into the 1-in. inlet of the sampler case and then insert the nozzle, which is flexible plastic tubing, into the adaptor.

- Run an extension cord from the nearest 110-V AC outlet (or generator) to the designated sampling location and plug in the hand vacuum.

  Note: If a generator is used to supply electrical power, place the generator outdoors in a location where exhaust fumes will not enter the dwelling. Non-leaded fuels should be used to the run the generator.

- Turn on the pump and vacuum the area of interest (Figure G-7) evenly in overlapping passes (at least 50% overlap), first left to right, then front to back over the entire designated area (Figure G-2). Vacuum the area again using this same pattern. For a 1-ft^2 area, vacuuming should not exceed 2 minutes.

  NOTE: THE CYCLONE SAMPLER CASE MUST BE HELD VERTICALLY THROUGHOUT THE VACUUMING PROCESS THROUGH THE REMOVAL OF THE FILTER CASSETTE.

  NOTE: The template that is used to defined a surface area to be vacuum is the potential source of cross contamination between samples. The template shall be thoroughly cleaned with disposable wipes between each sample.

- When the vacuuming is complete, turn off the hand vacuum, keeping the sampler case vertical.

- Raise the humidity in the sampler case (body) by slowly blowing three breaths into the nozzle using the separator as shown in Figure G-8. (Each field team member that is performing the sampling job should have his own personal separator.) Tap the sampler case smartly three times with a small rod (a screw driver is an example).

Figure G-6. Affixing Nozzle to Cyclone Dust Collector

Figure G-7. Sampling with Cyclone Dust Collector

Figure G-8. Separator and Its Use

- While maintaining the filter cassette in a upright position, carefully remove the nozzle and disconnect the tygon tubing.

- Replace the top section of the cassette and red outlet plug.

- Return the filter cassette to its original prelabeled ziplock plastic bag (inner bag) and seal. Place the sealed sample and the remaining barcode labels inside the outer ziplock bag and seal.

- Remove the vinyl gloves and dispose in the black trash bag.

- Store samples in a clean container until they are shipped to the lab via Federal Express Economy Distribution Service (formerly called Standard Air). Do not ship the settled dust samples in the same container as the soil samples.

5.1 Vacuum Sampling of Dusts on Floor Samples

Vacuum sampling of floor surfaces will be conducted at the front entryway, rear entryway, and along the perimeters of rooms designated by the field team leader. A 1-ft^2 template will be used to define the area to be sampled. The template will be positioned at the initial sampling site designated by the field team leader and vacuum sample will be collected in accordance with the protocol presented in Section 5.0. The template is a potential source of cross contamination between samples; therefore, it shall be thoroughly cleaned with disposable wipes after each sample is collected. A 1 in. rigid nozzle will be the standard nozzle for this activity.

5.2 Vacuum Sampling of Dusts on Window Channels and Stools

Vacuum samples will be collected as specified by Battelle's field team leader. The window sill is defined as the horizontal board outside the window stool, with its channel being that surface below the window sash and inside the screen and/or storm window. The entire available surface area will be measured with a steel tape and then vacuumed using the protocol described in Section 4.0. The dimensions of the area sampled will be recorded on the Field Sample Log. The size nozzle should also be recorded.

5.3 Vacuum Sampling of Dust Inside Air Ducts

If vacuum samples are to be collected inside air ducts of forced air or gravity air heating or cooling systems, they will be collected at the air outlets designated by the field team leader. The air diffuser or register will be removed from the air outlet to gain access to air duct. The area to be vacuumed will be measured with a steel tape. The dimensions of the area sampled will be recorded on the field sample log. In most cases sampling will need to be done with the 1/2-in. or 3/8-in. flexible nozzle.

The size and shape of the duct may limit access to the interior of the duct; therefore, it may be difficult to fit the vacuum nozzle inside the duct or make an exact measurement of the area vacuumed. If direct measurement of the vacuumed area is not possible, estimate the surface area sampled. Note on the field sample log if the surface area was estimated rather than directly measured. Describe the method of sampling in the field sample log.

6.0 COLLECTION OF SIDE-BY-SIDE SAMPLES

Two vacuum samples will be collected side-by-side of the same matrix in accordance with the QAPjP. The samples will be collected using the same protocol as described above. In order to link the sampling data of the co-located samples, the I.D. number of each of the samples must be indicated on the sampling data form of the sample collected adjacent to it. This will create the bridge between the two data sets. These side-by-side samples will be handled and shipped with the regular samples.

7.0 PREPARATION OF FIELD BLANK SAMPLES

Field blank samples will consist of a filter cassette that is handled in the same manner as the regular vacuum samples except that no sample is collected.

8.0 PREPARATION OF TRIP BLANK SAMPLES

Trip blank samples will consist of a filter cassette that is handled in the same manner as the regular vacuum samples except that it is not loaded into the pickup nozzle and no sample is collected. All unused filter cassettes in the shipping container with the exception of field blanks, will be designated as trip blanks. The following procedure will be used:

- Remove two barcode labels from a vacuum sampling kit and affix one to the field sample log and the other to the sample traceability record.

- Don a pair of powderless vinyl gloves prior to handling preweighed filter cassettes. <u>Do not touch the preweighed cassettes with bare hands</u>.

- Remove the prelabeled filter cassette from the inner ziplock plastic bag. Compare the sample number on the cassette with the barcode label number. These numbers should all match. If they do not match discard the sampling kit.

- Return the filter cassette to its original ziplock plastic bag (inner) and seal. Place the sealed sample inside the outer plastic bag and seal. The cassette is not loaded into the vacuum sampler and no sample is collected.

- Repeat this procedure for all unused cassettes in the shipping container, except for field blanks.

- Remove the vinyl gloves and discard in the black trash bag.

- Store and ship the trip blanks with the other vacuum samples.

9.0 CONTAMINATION AVOIDANCE

The following work practices will be instituted to prevent cross contamination between the dwellings sampled and between each sample collected within each dwelling:

- Each member of the field team will don disposable shoe coverings prior to entering the dwelling.

- Soil samples will not be collected until all dust samples are collected within the dwelling.

- Clean vinyl gloves (powerless) will be donned prior to collecting each vacuum sample and will be disposed of after each sample is collected.

- Preweighed filter cassettes must not be handled without the use of vinyl gloves to prevent the disposition of residues that may interfere with gravimetric analysis of the sample. If the filter cassette is inadvertently touched prior to collecting the sample, the filter cassette will be discarded. If a filter cassette is touched with bare hands or dropped after it has been used to collect a sample, the incident will be recorded on the Sampling Data Form. At the direction of the Battelle team leader, a substitute sample may be collected.

- The vacuum nozzle is cleaned with soapy water or "Wash-a-bye Baby" brand disposable wet wipes between each sample. Vinyl gloves will be used when cleaning nozzles and changed to a clean pair prior to collecting samples. There should be an adequate supply of clean nozzles to accommodate all the vacuum samples collected in one day (27 per dwelling times 2 dwellings per day).

- The templates will be cleaned with a "Wash-a-bye Baby" brand disposable wet wipe between each sample.

- Any electrical cords used outdoors, such as for connection to a generator, shall be cleaned prior to using them inside the dwelling.

10.0 DEVIATIONS FROM FIELD SAMPLING PROTOCOLS

Every attempt shall be made to follow this sampling protocol. Deviations from the sampling protocols may compromise the data quality and completeness objectives of the project. Deviations from the protocols will generally fall into two categories; inadvertent deviations (procedural errors), and deliberate deviations (modifications to the protocol in response to unusual conditions encountered in the field).

In the case of inadvertent deviations from the protocol, the sampling team shall fully document the deviation on the sampling data form and immediately notify the Battelle team leader and the MRI work assignment leader. Corrective action(s) shall be taken to ensure that the situation is not repeated. If possible, samples affected by the inadvertent deviation should be recollected in accordance with the specified protocol prior to leaving the site.

Deliberate deviations from the sampling protocol must be approved in advance with a signed modification to the QAPjP. If time is critical, preliminary verbal approval may be granted by EPA, Battelle, and MRI. These verbal approvals will be followed up with a signed modification to the QAPjP. In either case, the sampling team should notify all parties concerned in a timely manner so that the approval mechanism can by expedited. The MRI work assignment leader or the

Battelle task leader is responsible for initiation of the QAPjP modification and acquiring the necessary approvals from EPA, Battelle, and MRI.

The Battelle team leader shall be notified by the sampling team when field conditions found at the sampling site do not allow full compliance with the protocol or when the protocol does not appear to apply to the situation. The condition/situation shall be fully documented in a laboratory notebook. The team leader will in turn notify the MRI work assignment leader and the Battelle task leader.

APPENDIX H

Protocol for Wipe Sampling of Settled Dust

PROTOCOL FOR WIPE SAMPLING OF SETTLED DUST

1.0 INTRODUCTION

Wipe samples of settled dust will be collected during the pilot study from uncarpeted floors, window channels, and window stools using commercially-available moistened disposable wipes ("Wash-a-bye Baby" brand). The Battelle team member will direct the MRI sampling team on the surfaces selected for sampling. The surfaces will be wiped using a sampling method that was developed by Dr. Farfel for his doctoral thesis at John Hopkins University, School of Hygiene and Public Health (Farfel, 1987). This sampling method is also found in the National Institute of Building Sciences "Guidelines for Testing, Abatement, Clean Up, and Disposal of Lead-Based Paint in Housing."

2.0 SAMPLING EQUIPMENT AND SUPPLIES

The following materials will be used to collect wipe samples:

- "Wash-a-bye Baby" wipes.
- Washable template (inside dimensions, 1 ft by 1 ft).
- Steel measuring tape.
- Marking pen.
- Wipe sampling kits.
- Tyvek shoe coverings.
- Disposable vinyl gloves (powderless).
- Large plastic bags (white color for unused sampling kits, caramel color or equivalent for used sampling kits, and black or dark green color for trash).
- Mailing labels.

3.0 WIPE SAMPLING KITS

The wipe sampling kits will consist of a 1-qt and 1-gal ziplock bags and 12 identical barcode labels. A barcode label will be affixed to the 1-qt ziplock bag. The 1-qt bag along with the remainder of the corresponding barcode labels will be inserted into the 1-gal ziplock bag and sealed. For the remainder of this protocol, the 1-qt ziplock bag will be referred to as the "inner" bag of the 1-gal ziplock bag will be referred to as the "outer" bag.

In addition, one sealed package of "Wash-a-Bye" baby brand wipes will be included with the kits. Wipe sampling kits will be provided to the field team by the Sample Custodian. The kits should be examined for breakage when received in the field but not opened until needed to prevent contamination of the sampling materials.

4.0 WIPE SAMPLING PROTOCOL

The following procedure will be used to wipe sample floor surfaces:

- Don disposable shoe covering prior to entering the dwelling.

- Surfaces to be wipe sampled will be selected by the Battelle team leader.

- Don a pair of clean, powderless, vinyl gloves.

- Remove an unused wipe sampling kit from the white plastic bag. Open the outer ziplock bag, remove one barcode label, and hand it to the Battelle team leader who will affix it to the sampling data sheet.

- Remove the seal on a package containing the wipes (if not already removed during previous sampling efforts), open the lid, start the lid dispenser, replace the lid, remove a several wipes, and discard them in the black trash bag. Use the next wipe from the container to collect the sample.

- Position a clean 1-ft^2 template on the surface to be sampled.

- Place the wipe flat on the surface within the sample area as defined by the template. Using an open flat hand with the fingers together wipe the marked surface in an overlapping "S" pattern, first side to side and then front to back so that the entire 1-ft^2 area is covered.

NOTE: For small, well defined surfaces (i.e., window channels and stools) see alternate wipe sampling procedure below.

- Fold the wipe in half with the sample side folded in and repeat the wiping procedure within the marked surface area on one side of the folded wipe.

- Fold the wipe again with the sample side folded in.

- Insert the folded wipe into the inner ziplock plastic bag and seal. Seal the outer ziplock bag.

- Remove the vinyl gloves and dispose in the black trash bag.

- Record site location, sampling location, date, time, etc. on the sampling data form (this function will be performed by the Battelle team leader).

The wipe sampling procedure must be modified for window stools and window channels due to their limited size and geometry. They are generally too narrow to accommodate a 1-ft^2 template and cannot be wiped using the flat-hand technique. The following procedure will be used to collect wipe samples from window channels and stools.

- Don a pair of disposable vinyl gloves.

- Remove an unused wipe sampling kit from the white plastic bag. Open the outer ziplock bag, remove one barcode label, and hand it to the Battelle team leader who will affix it to the sampling data sheet.

- Remove the seal on a package containing the Chubbs wipes, open the lid, remove a few wipes, and discard them in the black trash bag. Use the next wipe from the container to collect the wipe sample.

- Place the wipe flat on the surface to be sampled. Holding the fingers together and flat against the stool, wipe the measured surface back and forth twice. Due to limited space, window stools will be wiped by applying pressure to the wipe using the fingertips.

- Fold the wipe in half with the sample side folded in and repeat the wiping procedure within the marked surface area on one side of the folded wipe.

- Fold the wipe again with the sample side folded in.

- Insert the folded wipe into the inner ziplock plastic bag and seal. Seal the outer ziplock bag.

- Remove the vinyl gloves and dispose in the black trash bag.

- Measure the length and width of the surface sampled. The Battelle team leader will record the data on the sampling data form.

5.0 COLLECTION OF SIDE-BY-SIDE WIPE SAMPLES

Two wipe samples will be collected side-by-side on the same surface. These samples will be collected using the same sampling technique as described above. In order to link the sampling data of the side-by-side samples, the I.D. number of each of the samples must be indicated on the sampling data form of the sample collected adjacent to it. In addition, the appropriate indication on the traceability form must also be made to transfer the information to MRI. This will create the bridge between the two data sets. These co-located samples will be handled and shipped with the regular wipe samples.

When wipe and vacuum samples are collected side-by-side, always collect the wipe sample first.

6.0 PREPARATION OF FIELD BLANK SAMPLE

The field blank will consist of a "Wash-a-bye Baby" wipe that are handled using the identical procedures used for the field samples except that no sample is collected. The following procedures will be used:

- Don a pair of disposable vinyl gloves.

- Remove an unused wipe sampling kit from the white plastic bag. Open the outer ziplock bag, remove one barcode label, and hand it to the Battelle team leader who will affix it to the sampling data sheet.

- Remove a few disposable wipes from the "Wash-a-bye Baby" container and discard them in the black trash bag. The next wipe will be used for the field blank.
- Fold the wipe in half twice.
- Insert the folded wipe into the inner 1-qt ziplock bag and seal. Seal the outer ziplock bag.
- Remove the vinyl gloves and dispose in the black trash bag.
- Store and ship the field blank with the regular field samples.

7.0 CONTAMINATION AVOIDANCE

The following work practices will be instituted to prevent cross contamination between the dwellings sampled and between samples collected within the dwelling:

- Each member of the field team will don disposable shoe coverings prior to entering the housing unit.
- Clean vinyl gloves (powderless) will be donned prior to collecting each wipe sample and will be disposed of after each sample is collected.
- The templates will be cleaned with a Wash-a-bye Baby disposable wet wipes between each use. After cleaning the template, remove the vinyl gloves and dispose in the black trash bag.
- The wipe sampling kits will be prepared by the Sample Custodian at MRI prior to shipment to the sampling site. The field team should not open the sampling kits until just prior to use.

8.0 DEVIATIONS FROM THE WIPE SAMPLING PROTOCOL

Every attempt shall be made to follow this sampling protocol. Deviations from the sampling protocols may compromise the data quality and completeness objectives of the project. In the pilot study, deviations from the protocols will generally fall into two categories; inadvertent deviations (procedural errors), and deliberate deviations (modifications to the protocol in response to unusual conditions encountered in the field).

In the case of inadvertent deviations from the protocol, the sampling team shall fully document the deviation on the sampling data form and immediately notify the Battelle team leader and the MRI work assignment leader. Corrective action(s) shall be taken to ensure that the situation is not repeated. If possible, samples affected by the inadvertent deviation should be recollected in accordance with the specified protocol prior to leaving the site.

Deliberate deviations from the sampling protocol must be approved in advance with a signed modification to the QAPjP. If time is critical, preliminary verbal approval may be granted by EPA, Battelle, and MRI. These verbal approvals will be followed up with a signed modification to the QAPjP. In either case, the sampling team should notify all parties concerned in a timely manner so that the approval mechanism can by expedited. The MRI work assignment leader or Battelle task leaders is responsible for initiation of the QAPjP modification and acquiring the necessary approvals from EPA, Battelle, and MRI.

The Battelle team leader shall be notified by the sampling team when field conditions found at the sampling site do not allow full compliance with the protocol or when the protocol does not appear to apply to the situation. The condition/situation shall be fully documented in a laboratory notebook. The team leader will in turn notify the MRI work assignment leader and the Battelle task leader.

APPENDIX I

Protocol for Composite Soil Sampling

PROTOCOL FOR COMPOSITE SOIL SAMPLING

1.0 INTRODUCTION

Soil samples will be collected with a clean soil recovery probe inserted into the ground to a depth of approximately 2 inches. The soil recovery probe consists of a 12-in stainless steel core sampler, replaceable 1-in I.D. butyrate plastic inserts, a cross-bar handle, and hammer attachment (Figure I-1). Composite samples consisting of three soil cores will be collected at each location specified in the QAPjP. The top 0.5 inch section of the soil cores will be composited at the site.

Some dwellings included in the survey may not have a lawn. The areas surrounding the structure may be paved with concrete or blacktop. For this situation, vacuum samples will be collected from the pavement. The protocols for both soil core sampling and vacuum sampling of pavement are presented below.

2.0 SAMPLING EQUIPMENT AND SUPPLIES

- 1 1/8-in diameter, stainless-steel, soil-recovery probe with cross-bar handle, 6-in length (Arts Manufacturing and Supply, American Falls, Idaho).
- AMS hammer attachment for hard, dry, or lightly frozen soils.
- 1-in diameter plungers with and without adjustable stop.
- Plastic straight edge (ruler).
- Clamp for holding liner (optional).
- Vinyl gloves (powderless).
- Soil sampling kits (one per sample)
- Large plastic bags (white color for unused sampling kits, caramel color or equivalent for used sampling kits, and black or dark green color for trash).
- Wash bottle.
- 95% Ethanol.

- Crescent wrenches (2) for disassembly of soil recovery probe.

Figure I-1. Soil Recovery Probe (Exploding Diagram)

3.0 SOIL SAMPLING KITS

Each soil sampling kit will consist of a plastic butyrate liner (1 in I.D.), two 1-gal ziplock plastic bags and twelve identical adhesive barcode labels. The plastic liner will come double sealed within the two ziplock bags. The inner bag will be prelabeled with one of the 12 barcode labels. The remainder of the adhesive labels will be contained in the outer plastic bag. The Sample Custodian will prepare soil sampling kits.

The field team will take possession of the sampling kits by signing the sample traceability record provided by the sample custodian. The kits should be examined for breakage when received in the field but not opened until needed to prevent contamination of the sampling materials.

4.0 SOIL SAMPLING PROTOCOL

The following protocol will be used for collecting the soil samples:

- Don a clean pair of powderless vinyl gloves.
- Remove an unused soil sampling kit from the white plastic bag. Open the outer ziplock bag and remove one corresponding barcode labels from the wipe sampling kit. Hand the label to the Battelle team leader who will affix it to the sampling data form.
- Disassemble a clean soil recovery probe (unscrew the soil probe section from the coupling).
- Open the inner ziplock bag of the soil sampling kit and remove the plastic liner.
- Remove the protective end caps from the plastic liner (the end caps are optional when the liner is sealed inside a ziplock bag).
- Insert the plastic liner into the probe.
- Reassemble the probe and attach the cross-bar handle or hammer attachment.

- Push the soil recovery probe into the soil at the designated sampling site to a depth of approximately 2 inches.

- Twist and snap the coring tool to one side and remove the core sample.

- Disassemble the probe and remove the plastic liner containing the core sample.

- Insert a clean 1-in diameter plunger into the top end of the liner.

- Push out all but 0.5 inches of the core from the liner with the plunger.

  Note: The plunger is equipped with an adjustable stop. The stop will be adjusted to prevent the plunger from advancing beyond 0.5 inches from the end of the liner. If necessary, the liner can be secured in a clamp during this procedure. The use of clamp is recommended when the sampling is performed by one person.

- Scrape the top of the liner with a clean straight edge to lever off soil that was pushed out of the liner. Discard the soil pushed out of the liner.

  NOTE: The soil can also be leveled off with a gloved finger. Experience has shown that this is a faster method.

- With a clean plunger (without stop), push the remaining 0.5-inch section of the core sample into the prelabeled ziplock bag.

  Note: A second plunger without an adjustable stop is used to push the remaining section of the core out of the liner.

- Reinsert the plastic liner into the soil recovery probe and reassemble the unit.

- Collect the remaining soil cores in the composite sample as per the QAPjP using the same method as described above. The three or five cores that constitute the composite sample are placed into the same ziplock plastic bag.

- Return the inner plastic bag containing the composite sample to the original outer ziplock plastic bag and seal.

- After each composite sample is collected, discard the plastic liner in the black trash bag.

- Wipe down the recovery probe, plungers, and straight edge with Wash-a-bye babe disposable wipes. Discard the wipes in the trash bag. If conditions are excessively cold, dampen each wipe prior to use with 95% Ethanol. This will help avoid ice buildup on the equipment from water present in the wipes.

- Remove the vinyl gloves and discard in the black trash bag.

- The Battelle team leader will record site location, sampling location, data, time, etc. on sampling data form.

- Ship soil samples to the laboratory via Federal Express Economy Distribution Service. The soil samples will be shipped in a container separate from the settled dust samples to prevent cross contamination between the sample types.

4.1 ALTERNATIVE SAMPLING PROCEDURES FOR HARD, DRY, OR FROZEN SOILS

The following is an alternate soil sampling protocol that will be used for soils that are hard, dry, or frozen.

- Remove the cross-bar handle from the soil recovery probe.

- Attach the AMS hammer to the probe.

  NOTE: Some field crew members may prefer using the hammer attachment for all soil samples.

- Grip the hammer attachment firmly and drive the probe into the ground to a depth of approximately 2 inches using an up and down motion.

- If conditions do not allow for full penetration to 2 inches, make every effort to penetrate to a depth of at least 0.5 inches. If the penetration is less than 2 inches, note the deviation from the protocol on the sampling data form.

5.0 COLLECTION OF SIDE-BY-SIDE SAMPLES

Two soil samples will be collected side-by-side in the same matrix in accordance with the QAPjP. The samples will be collected using the same protocol as described above. In order to link the sampling data of the side-by-side samples, the I.D. number of each of the samples must be indicated on the sampling data form of the sample collected adjacent to it. In addition, the appropriate indication on the traceability form must also be made to transfer the information to MRI. This will create the bridge between the two data sets. These co-located samples will be handled and shipped with the regular soil samples.

6.0 PREPARATION OF FIELD BLANKS FOR THE SOIL SAMPLING PROCEDURE

Field blank samples will consist of a core liner that are loaded into the soil recovery probe and handled in the same manner as the regular samples except no soil sample is collected. The following procedure will be used:

- Don a pair of powderless vinyl gloves.
- Remove one corresponding barcode labels from an unused wipe sampling kit (outer ziplock bag). Hand the label to the Battelle team leader who will affix it to the sampling data form .
- Remove the plastic liner from the inner ziplock bag.
- Remove the end caps from the plastic liner.
- Disassemble the soil recovery probe that has been cleaned and insert the liner into the probe .
- Reassemble the probe.
- Disassemble the probe and remove the plastic liner without collecting a sample.
- Insert the clean plungers into the liner by the same method that is normally used to extract the core from the liner.

- Scrape the top of the liner with a clean straight edge lever or with gloved finger (as done during the sampling procedure).

- Replace the end caps on the liner.

- Place the capped liner inside the original prelabeled ziplock bag.

- Return the inner plastic bag containing the blank sample to the original outer zip-lock plastic bag and seal.

- Remove the vinyl gloves and dispose in the black trash bag.

- Ship field blanks with the other soil samples to the laboratory.

7.0 VACUUM SAMPLING OF PAVEMENT SURROUNDING THE DWELLING

Vacuum samples of dirt from pavement (concrete, brick, blacktop, etc.) will be collected with the cyclone dust collector shown in Appendix I.

The pavement will be vacuumed in the same manner as collection of indoor dust vacuum samples described in Appendix I. Refer

to the protocols in Appendix I for collection of this type of sample.

8.0 CONTAMINATION AVOIDANCE

The following work practices will be instituted to prevent cross contamination between each composite soil sample collected:

- Soil and vacuum samples of exterior pavement should not be collected until all dust samples are collected within the house.

- Clean vinyl gloves (powderless) will be donned prior to collecting each sample and will be disposed of after the sample is collected.

- The soil recovery probe, plungers, and straight edge will be cleaned with wet disposable wipes between each composite sample.

- Preweighed filter cassettes must not be touch with bare hands. Use powderless vinyl gloves to prevent the disposition of residues that may interfere with gravimetric analysis of the sample.

- The vacuum nozzle will be cleaned with soapy water or disposable wet wipes between each sample. Vinyl gloves will be used when cleaning nozzles and changed to a clean pair prior to collecting samples. There should be an adequate supply of clean nozzles to accommodate all the vacuum samples collected in one day.

- The templates will be cleaned with Wash-a-bye Baby disposable wet wipe between each sample. Vinyl gloves will be used to cleaned templates and changed to a clean pair prior to collecting samples.

10.0 DEVIATIONS FROM FIELD SAMPLING PROTOCOLS

Every attempt shall be made to follow this sampling protocol. Deviations from the sampling protocols may compromise the data quality and completeness objectives of the project. Deviations from the protocols will generally fall into two categories; inadvertent deviations (procedural errors), and deliberate deviations (modifications to the protocol in response to unusual conditions encountered in the field).

In the case of inadvertent deviations from the protocol, the sampling team shall fully document the deviation on the sampling data form and immediately notify the Battelle team leader and the MRI work assignment leader. Corrective action(s) shall be taken to ensure that the situation is not repeated. If possible, samples affected by the inadvertent deviation should be recollected in accordance with the specified protocol prior to leaving the site.

Deliberate deviations from the sampling protocol must be approved in advance with a signed modification to the QAPjP. If time is critical, preliminary verbal approval may be granted by EPA, Battelle, and MRI. This verbal approval will be followed up with a signed modification to the QAPjP. In either case, the sampling team should notify all parties concerned in a timely manner so that the approval mechanism can by expedited. The MRI work assignment leader or Battelle task leader is responsible for initiation of the QAPjP modification and acquiring the necessary approvals from EPA, Battelle, and MRI.

The Battelle team leader shall be notified by the sampling team when field conditions found at the sampling site do not allow full compliance with the protocol or when the protocol does not appear to apply to the situation. The condition/situation shall be fully documented in a laboratory notebook. The team leader will in turn notify the MRI work assignment leader and the Battelle task leader.